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Influence of alkali carbonate reaction on compressive strength of mortars with air lime binder

P. Štukovnik [a], M. Marinšek [b], B. Mirtič [c], V. Bokan Bosiljkov [a,*]

[a] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Jamova 2, 1000 Ljubljana, Slovenia
[b] University of Ljubljana, Faculty of Chemistry and Chemical Technology, Aškerčeva 5, 1000 Ljubljana, Slovenia
[c] University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia

HIGHLIGHTS

- The ACR occurs also in lime mortars, when reactive dolomite is used as aggregate.
- The presence of OH^- ions in the binder is sufficient to trigger and promote the ACR.
- The ACR increases compressive strength of lime mortars.
- Precipitation of secondary calcite during ACR is the cause of the strength increase.
- This precipitation increases the density of lime binder along dedolomitized grains.

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ABSTRACT

This paper investigates the process of alkali-carbonate reaction (ACR) in air lime mortar prepared with Triassic dolomite aggregate. The progress of the ACR at various exposure conditions, i.e. accelerated conditions of 1 M NaOH at 60 °C, distilled water at 60 °C, and 1 M NaOH solution at 20 °C, and reference conditions (water at 20 °C) was studied using petrographic microscope and scanning electron microscopy with X-ray microanalysis (SEM/EDS). As a control, an air lime mortar with inert limestone aggregate was prepared and submitted to the same conditions. Parallel and complementary to the microscopic investigation, the compressive strength, weight and length of the mortar bars was measured over the exposure time. The results of the tests indicate that the presence of hydroxide ions in the binder is sufficient to trigger and promote the ACR in the lime mortar with dolomite aggregate. More alkaline conditions brought about by alkali hydroxides and the higher temperature of 60 °C accelerate the reaction. Compressive strength of the lime mortar with dolomite aggregate, exposed to water or the NaOH solution, increased with time considerably, as a consequence of the progressing ACR.

1. Introduction

Before Portland cement was introduced to the market, air lime used to be traditional binder all over Europe for a large variety of mortars (for brickwork, stonework, renders and plasters) and lime washes. When resistance of mortar against the action of water was demanded, pozzolanic materials such as volcanic ash, crushed brick or pottery were added to the air lime in order to produce hydraulic binder. In particular, the Classical Greeks, and especially the Romans, are credited for the development of hydraulic binders [1–3]. Since Portland cement was first available, builders increasingly used this hydraulic binding material for the following reasons: setting and hardening speed, high strength, and resistance to water. Eventually, this standard industrial product superseded local lime-burner manufactures.

Today, lime has been rediscovered due to the rehabilitation campaigns of old town centres and other important historical buildings. This rediscovery is of great consequence because it addresses some technical concerns: i.e. reaction and compatibility with materials used to build original constructions. It is also linked to aesthetic issues as well as to a new awareness and concern about heritage: monumental, traditional and minor heritage.

Lime used to be the traditional binder also in Slovenia. Small-scale production, sufficient for local community needs, was typical for the country. The lime kiln from Goričko, Slovenian region between the Austrian and Hungarian borders, made from limestone blocks and clay bricks, is a typical representative of the local

* Corresponding author.
E-mail address: violeta.bokan-bosiljkov@fgg.uni-lj.si (V. Bokan Bosiljkov).

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community lime kilns (Fig. 1). Fortunately, there are still some small lime kilns all over Slovenia that are producing quick lime and lime putty in the traditional way. Therefore, limited amounts of traditional dolomite (mainly) or calcite (rarely) lime putty for the preparation of lime mortars and lime washes are still available.

Lime mortars are composed of lime binder, aggregate and water, and for certain applications also of mineral and/or organic additives. The origin of aggregate grains forming the filler of historical lime-based mortars is predominantly from local deposits or streams with rounded or angular grains [4]. In some cases also crushed bricks were added as aggregate [5].

When preparing new lime-based mortar for restoration/conservation works (repair mortar), several demands have to be fulfilled. Repair mortar should be durable, practical in application and should not have any negative effect on the durability of the existing historical building [6,7]. Restoration and re-integration are based upon respect for original materials [8]. Properties and characteristics of repair mortar, such as workability, porosity, strength, shrinkage and durability mainly depend on the nature of the binder component [9–11], while on the other hand, strength characteristics, dimensional stability and durability of repair mortar also depend on the aggregate type being used [1,10,11]. It is common agreement that crushed aggregate with angular grains is the best choice for the production of repair mortar with air lime binder.

In Slovenia the majority of aggregates used for mortar production originate from carbonate rocks, limestone, dolomitic limestone, calcic dolomite and dolomite, according to the classification of rocks given in [12]. For certain dolomite rock used as the aggregate source an unusually fast increase in compressive strength over time was observed with Portland cement binders [13], while other mixtures of identical composition, apart from the aggregate origin did not show a similar behaviour. Detailed study of this concrete's microstructure was carried out and revealed the presence of the ACR [14,15].

In order to follow the process of the ACR reaction in mortar between hydroxide ions from the binder and the dolomite aggregate

Fig. 1. Lime kiln from Goričko.

grains in more detail, we prepared mortars with very different binders. Among them were also mortars with air lime binder in the form of lime putty produced in traditional way. The mortars' bars were exposed to the same exposure conditions as already used for the mortars with Portland cement binder [14,15]. For comparison purposes we also used a second aggregate, very pure and inert crushed limestone aggregate. The results obtained not only improved our knowledge of the ACR reaction, but also discovered a possible new mechanism to impart to air lime mortars resistance against the action of water at normal or elevated temperatures.

2. Materials and methods

2.1. Materials

Two different mortar mixtures were prepared using the lime binder and crushed sand fraction 0/4. The first mixture (mortar L) consists of limestone and the second mixture (mortar D) of dolomite aggregate. Properties of both aggregates used and microscopic petrographic analysis of parent rocks are given in [15]. The binder in the form of lime putty was prepared in traditional way from soft burnt limestone and aged for more than 1 year. It consists of minerals Portlandite ($Ca(OH)_2$), Calcite ($CaCO_3$) and Brucite ($Mg(OH)_2$). Volume ratio between sand and lime putty in the mortars is 3:1, and the water amount was adjusted in order to obtain mortars with plastic consistency and good workability, measured by flow table test as defined in standard SIST EN 1015-3 [16]. The flow value of fresh mortars was 13 ± 2 cm.

The mortar bars (40 × 40 × 160 mm) were prepared according to standard SIST EN 1015-11 [17]. For each mortar mixture, exposure condition and physical and mechanical test three mortar bars were cast. The bars were demoulded after 7 days and put on supporting system allowing uniform access of air to all surfaces of mortar bars. Then the bars were left in the laboratory conditions (temperature of 20 °C ± 3 C and relative humidity of 60 ± 5%) for 3 months. Subsequently the mortar bars were exposed to the different curing conditions to accelerate the ACR, as already described in [14,15]: 1 M NaOH solution at 20 °C, 1 M NaOH solution at 60 °C and distilled water at 60 °C. The reference control condition was chosen to be distilled water at 20 °C. Already Min et al. [18] pointed out that the rate of the ACR is dependent on the pH and temperature of the solution. It is common knowledge that the submerging of the bars into aqueous media with various pH values is detrimental for the non-hydraulic lime binder, although completely carbonated, where the increased temperature up to 60 °C additionally accelerates the decomposition of lime mortars. However, in the presence of dolomite aggregates the conditions of curing as described above accelerate the progress of the ACR within laboratory measurable time. Therefore, we accepted possible detrimental influences of the used exposure conditions to physical and mechanical characteristics of hardened lime mortars, in order to finish the study in 1 year. The names of samples are given in Table 1.

2.2. Testing methods

Physical and mechanical tests on mortar bars were performed at 20 °C. Prior to the physical and mechanical tests the samples were cooled down to 20 °C, while maintaining the saturated state of the specimens. Change in weight of the bar specimens with time was measured using a balance with full capacity of 4200 g and resolution of 0.01 g. The length change of mortar bars was measured by length comparator consisting of a high-grade dial micrometre with measuring range of 0–12.5 mm and resolution of 0.001 mm. An Invar® reference bar (40 × 40 × 160 mm) was used for checking the measuring device, before and after each set of readings. Compressive strength was determined according to the standard SIST EN 1015-11 [17], by universal testing machine Roell-Amsler with a capacity of 100 kN.

A polarizing optical microscope, NIKON Eclipse E 200, working in transmission mode was used for the examination of thin sections. Thin sections were prepared from the mortar bars, in order to detect changes or damage in the microstructure of each mortar.

Table 1
Names of samples.

	Limestone	Dolomite	H_2O	NaOH	20 °C	60 °C
L_H2O_20	x		x		x	
L_SH_20	x			x	x	
L_H2O_60	x		x			x
L_SH_60	x			x		x
D_H2O_20		x	x		x	
D_SH_20		x		x	x	
D_H2O_60		x	x			x
D_SH_60		x		x		x