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Research paper

# The effect of the substitution of hydrated lime with phyllite on mortar quality

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ABSTRACT

In Brazil, phyllite began to be used as a substitute for hydrated lime for binary cement/lime mortar. Phyllite is cheaper and contributes more to the health of the workers than hydrated lime. However, this substitution has generated problems in coatings. Here we evaluate the effect of this substitution on a binary cement/phyllite mortar quality. The cement:phyllite:sand ratio tested was 1:0.4:6.5, which is the more common ratio used in Brazil, providing greater savings. The chemical and mineralogical compositions of hydrated lime and phyllite as well as some mortar properties were characterized. Overall, our results show that phyllite mortars have greater porosity, lower linear retraction, and lower pullout strength. These characteristics are due to the properties of expansion and retraction of the material and the absence of lamellar structure in hydrated lime. Although phyllite has been used as a substitute for hydrated lime due to economic and health reasons, our study indicates that the contribution of phyllite for mortar quality is lower than that of lime, therefore decreasing mortar quality rather than improving it.



## 1. Introduction

Mortar is a mixture of binder (cement or lime), mineral aggregates with fine granulometry (sand), and water, with a capacity for hardening and adherence (Guimarães, 2002; Gleize et al., 2003). Two types of limes are used to make mortars: hydraulic lime (natural hydraulic, formulated or hydraulic lime) or air lime (EN 459-1:2011, 2011). According to EN 459-1:2011 (2011), hydrated lime is composed primarily of calcium oxides (CaO) or calcium hydroxides [$Ca(OH)_2$] and smaller fractions of magnesium oxides. Then, this kind of lime confers water retention and workability properties to the mortars when in the plastic state (Hendry, 2001; Silva et al., 2006). Although water retention is related to the reaction times of mortar hardening and the degree of hydration of the cement, maintaining the plastic state of the mass (Hendry, 2001), workability is related to the consistency and plasticity of the mortar. Mortar plasticity affects the degree to which it spreads on the surface of the substrate (Haach et al., 2011).

The quality of lime is regulated by the Brazilian Standard (Norma Brasileira (NBR) 7175) (ABNT, 2003), which follows the same criteria as the American Society for Testing and Materials (ASTM) C206-03 and C207-06 (ASTM — American Society for Testing and Materials, 2007a,b,c). Binary cement/hydrated lime mortars have greater deformability (low modulus of elasticity), which leads to better absorption of initial accommodations of the structure (Paiva et al., 2007). These mortars have the capacity to cover small cracks in coatings, which occur over time, due to mortar retraction (Izaguirre et al., 2011; Binici et al., 2012). This retraction results from water evaporation and carbonation reaction (Binici et al., 2012) of the lime, in which carbonic gas ($CO_2$) from the air penetrates the pores of the mortar with relative ease. If there is moisture in the coating, $CO_2$ reacts with the calcium hydroxide [$Ca(OH)_2$] of the mortar, forming calcium carbonate [$CaCO_3$] and water [$H_2O$] (Arandigoyen et al., 2006), according to Reaction 1:

$$Ca(OH)_{2(s)} + CO_{2(g)} \leftrightarrow CaCO_{3(s)} + H_2O_{(aq)} \quad (1)$$

Recently, in some Brazilian regions, such as the Southeast, South and Midwest, phyllite began to be used as a substitute for hydrated lime, which is generally used in mortars. The phyllite used for this purpose is used due to the lower acquisition cost relative to hydrated lime. This difference is because phyllite is a granulated metamorphic rock (Arnold et al., 1998).

Additionally, the effect of using phyllite in the mortar must be similar to that provided by lime when the mortars are in the plastic state (Souza et al., 2009). Therefore, the water retention and workability of mortars produced with phyllite are similar to the mortars formulated with lime (Romano et al., 2011). In contrast to hydrated lime, phyllite does not cause accentuated drying of the hands of the workers, and its particles do not disperse in the air, decreasing the inhalation of the product and thus contributing to the health of the workers.

Another advantage of phyllite is that it has been used in lower proportions than hydrated lime. Although this must vary between traces,

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from 1:2:8 (cement:lime:sand) and 1:2:11 (Isaia et al., 2007), the recommended trace for phyllite, according to the manufacturer, is 1:0.4:6.5 and 1:1:8 (cement:phyllite:sand; traces in volume), providing greater savings.

Although these advantages justify the increased use of phyllite in mortars, the Brazilian standard (ABNT — NBR, 13529, 2013) does not consider this additive to be a binder. Phyllite is considered a mineral plastifying additive, potentially not providing the same properties that hydrated lime provides for the mortars. Thus, mortar quality control results (in Brazil) indicate that the addition of phyllite in some brands was the cause of problems reported by consumers due to poor quality (John, 2003). Additionally, there are no reports in the scientific literature of the technical specifications for the use of phyllite in mortars. In Ghana, Africa, a study was performed in which phyllite was added to the trace of concrete as a coarse aggregate in the making of beams. The results indicated that the beams made with concrete containing phyllite did not resist shear stresses (Adom-Asamoah and Afrifa, 2011). In Almeria, Spain, phyllite is used for waterproofing roofs, sealing liners of irrigation ponds, and as a core material of small earthen zoned dams (Gárzon et al., 2010). The use of natural materials such as phyllite in excessive concentrations, however, can lead to the formulation of mortars with excellent performance in the plastic state but failures in performance in the hardened state due to accentuated hydraulic retraction and consequent cracking (John, 2003; Romano et al., 2011). According to Bauer (2008), this type of additive (mineral) may not provide adequate connection of the aggregates, and when the hardened mortar suffers expansions or contractions, the coating can disaggregate with relative ease (detachment with dustiness) and cause cracks. These are technical reports and indicate the absence of scientific studies that relate the properties and characteristics of mortars produced with this additive, justifying the need for studies on the subject.

With this study, the chemical composition and morphological structure of phyllite and hydrated lime were characterized, as well as the physical properties of some binary cement/binder mortars containing these materials, with the objective of evaluating the effect of substituting lime with phyllite on mortar quality.

## 2. Materials and methods

### 2.1. Evaluated materials

CH-III hydrated lime and CPII-Z-32 Portland cement from the Brazilian market were used and certified by the national standards NBR 7175 (ABNT, 2003) and NBR 11578 (ABNT, 1997), respectively. NBR 11578 follows the standards of the ASTM C150-12 (ASTM — American Society for Testing and Materials, 2012a,b). The phyllite was acquired from Ecocal Indústria e Comércio de Cal Ltda® and the sand used was a quartz from the Paraná River Basin.

In all of the determinations performed in the mortars, the measures of the traces used were in volume, and the proportion of water:cement was 0.88. For mortars with hydrated lime, the trace was 1:2:8 (cement: lime:sand), and for mortars with phyllite, the cement:phyllite:sand proportion was 1:0.4:6.5, as recommended by the manufacturer. The cylindrical specimens (SPs) were then curing in a covered environment for 60 days. The consistence of mortars (made with the trace proportions informed above) was obtained according to ASTM C1437-13 (ASTM — American Society for Testing and Materials, 2013a,b) standards. The consistency of 215 ± 1.30 and 239.60 ± 2.70 mm was found for hydrated lime and phyllite mortars, respectively.

### 2.2. Chemical, mineralogical, and morphological characterization of phyllite and lime

Phyllite and lime samples were crushed with a porcelain mortar and pestle. The mineral composition was examined by X-ray diffraction (D2 Phaser diffractometer from Bruker with CuKα radiation, $\lambda = 1.5418$ Å, between 5° and 80° of 2θ, sweeping velocity of 0.10 $s^{-1}$ in 2θ, and in a rotating sample holder at 5 rpm).

To evaluate the morphology, aliquots of the crushed samples were examined by scanning electron microscopy (SEM). The samples were suspended in isopropanol and directly dripped into the aluminum sample holder (stub) from where images were obtained on a Hitachi microscope, model TM 3000, operating with a 15 kV beam. The chemical composition was only obtained using a Hitachi Swift ED3000 Energy Dispersive Spectrometer (EDS) coupled to SEM. EDS was performed throughout the image, in the entire sample using a 15 kV light beam.

### 2.3. Physical analyses

The water absorption, void fraction, density, linear retraction, and tensile bond strength of the mortars were measured to compare the quality of mortars made with lime or phyllite. The water absorption and void fraction of the mortars were evaluated using the ASTM C642-13 methodology (ASTM — American Society for Testing and Materials, 2007a,b,c). For this, 3 cylindrical specimens (SPs) were molded, with a height of 20 cm and a diameter of 10 cm, using a mortar with phyllite and one with hydrated lime. The test was performed in triplicate 60 days after confection of the SPs. The water absorption of the mortars was calculated from the relationship between the dry mass of the SPs, measured after drying in a forced air oven at 100 °C for 48 h, and the wet mass, measured after three days of immersion in water at 22.5 °C and pH of 8.45. The void fraction was obtained through the relationship between the dry and wet masses after immersion in boiling water (approximately 100 °C) for 4 h.

The test to determine the specific mass of the grains in the hydrated lime and phyllite followed the procedure of the ASTM D854-10 (ASTM, 2006), with samples in triplicate. In these tests, 50 g of each sample was immersed in distilled water for 12 h and agitated in a dispersion device for 15 min after immersion. The resulting mixture was placed in glass flasks and heated in a water bath to a temperature of approximately 100 °C for 30 min.

The linear retraction measurements were made according to the ASTM C531-00 (ASTM — American Society for Testing and Materials, 2012a,b). The SPs had a square cross section of 2.5 cm and a length of 28.5 cm, with 2.5-cm pins at each end. After molding of the SPs, the SPs remained in wet curing for 24 h (90% humidity) to avoid the phenomenon of retraction in the period prior to removal from the mold and measurements. The measurements were made daily for 15 days with a digital length comparator device.

For the tensile bond strength measurements, two 50 × 50 cm masonry panels were made: one coated with mortar containing phyllite and the other containing hydrated lime. The procedure used followed NBR 13528 (ABNT, 2010), based on procedures adopted by the ASTM C1583-13 (ASTM — American Society for Testing and Materials, 2013a, b). After curing of the coating mortar, the wet cutting of the SPs was performed. For this, the tablets, with a diameter of 50 mm, were collected over the locations of the cut after drying of the mortar. The rupture load of the SPs was obtained using a dynamometer.

## 3. Results and discussion

### 3.1. Density

The density of the phyllite grains and hydrated lime was 2.58 g/$cm^3$ and 2.59 g/$cm^3$, respectively.

The values obtained with the hydrated lime and phyllite samples were similar to those reported in other studies (Cardoso et al., 2009; Souza et al., 2009; Melo and Thaumaturgo, 2012). The density of phyllite was lower than that of the samples from Spain, whose values were between 2.75 and 2.82 g/$cm^3$ (Gárzon et al., 2010). This discrepancy in values is probably related to the mineral components of the rock,