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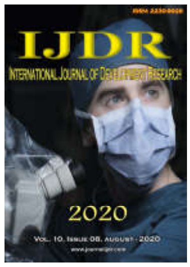

RESEARCH ARTICLE

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ECO-EFFICIENT EARTH PLASTERS: EFFECT OF COW DUNG AND AIR LIME ON A KAOLINITIC CLAYISH EARTH

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ABSTRACT

Earth mortars are eco-efficiently used as plasters, but not all raw earth have a composition and behavior to meet the plasters nowadays requirements. Since long time ago, some stabilizing materials are often added to improve some characteristic of the earth mortars. Thus, to compare the performance of an industrial stabilizer recognized by the literature with a natural stabilizer already established by the Brazilian vernacular construction tradition, this research compared the effects caused by the addition of hydrated air lime and cow dung on the physical and mechanical properties of an earth mortar produced with a Kaolinitic Clay Earth (KCE). For this purpose, laboratory tests were carried out, following the guidelines of the German standard DIN 18947 for the analysis of earth plastering mortars. The results show that the earth mortars stabilized with cow dung presents superior results in all tests performed. Therefore, this is a material with great potential to be investigated as a stabilizer in earth plastering mortars.

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INTRODUCTION

In other locations in South America it is possible to find millennial constructions made with earth building techniques made by ancient civilizations. However, it is believed the earth building technologies were introduced in Brazil during the colonial period (from the 1early 6th century), since there is no evidence that natives indigenous used the earth as a building material (Rezende *et al.,* 2013). Since then, earth construction has spread across the country and is still practiced today. In order to improve the behavior of earth constructions, many additions have historically been used to stabilize the clayish raw earth, with air lime being considered one of the most compatible stabilizers. Earth plastering mortars are made of a mix or sieved earth with water. An earth is composed of clay, silt, sand and coarse particles. Sieving is needed to remove the coarse particles, so that the remaining aggregates are compatible with plaster thicknesses. When the clayish fraction is high, supplementary sand may be added. The characteristics of the earth mortars strongly depend on the clay type and content (Lima *et al.,* 2020). Faria (2004) explains that the calcium hydroxide ($Ca(OH)_2$), main constituents of the hydrated air lime, performs covalent bonds with the hydroxyls (OH) of the clays, promoting bonds. Thus, as the clay retains water by ionic bonds, with the presence of lime in a mortar, the clay has no more electrons available to make connections with the water and, therefore, the water is no longer retained by the clay.

In addition, during the drying of an earth mortar stabilized with lime, carbonation of the lime occurs, where it incorporates CO_2 present in the air and returns to its initial chemical configuration. Depending on the content of air lime, this process consolidates a rigid and porous structure, which makes the mortar more resistant to the action of water, and still maintains the permeability of the plaster, allowing the masonry to release and absorb moisture without deteriorating the substrate (Santos *et al.*, 2017). However, since the extraction process of liestone to the calcination on high temperature ovens (900ºC), the lime production process is relatively polluting (Cunha, 2015); not in comparison to gypsum but with cement. In Brazil and many other regions of the world (Bamogo *et al.*, 2020), cow dung is another material with vernacular tradition as earthen construction stabilizer, from pavements to renders. Until nowadays, this is a building tecnology used and recognized by populations and transmitted orally (Pachamama, 2018). Recent researchs (Millogo *et al.,* 2016) (Bamogo *et al.,* 2020) clarifies that cow dung is rich in nitrogen, phosphorus, phosphoric acid and potassium. And when it is add to clayish earth mortars, these components react with kaolin and quartz present in the clayish earth, resulting in insoluble silicate amines. These compounds consolidatesthe components of the mixture providing water resistance and hardness. In addition, the fibers present in the cow dung also difficult the drying shrinkage and reduce the formation of cracks, which contributes to increased mechanical strength, including adhesion.

Thus, in the Brazilian context and in countries with large cultures of this animal, cow dung may be a suitable option for the stabilization of earth mortars, whether in traditional communities or in commercial works. In addition, cow farming, a culture brought during the colonial period, generates a large volume of cow dung produced daily, with a high potential for water contamination with improper disposal, as recorded in the report by the Food and Agriculture Organization of the United Nations (FAO, 2006). In this sense, in addition to its compatible structural qualities for stabilizing earth mortars, cow dung is a residual material that can be a more eco-efficient alternative than the use of air lime. For this reason, the objective of this research is to evaluate the physical and mechanical properties of earth mortars produced with kaolinitic clayish earth using two materials as stabilizers to compare the difference in the effects caused. To assess the physical and mechanical properties of the earth mortars, tests and parameters indicated in the German standard DIN 18947 (DIN, 2018) specific for eath plasters, were used. This standard refers to several parts of the EN 1015 (CEN, 1999) several parts standards.

MATERIALS AND METHODS

Materials: In the composition of the mortars, a Kaolinitic Clayish Earth (KCE) collected in the rural area of Itabirito city in the state of Minas Gerais, Brazil, was used. The earth was sieved in field with a mesh with an opening of 2.79 mm. After air drying, the sieved earth was taken to the laboratory where it was sieved again according to the requirement of each stage of soil mineralogical and granulometric characterization. A washed sand of medium granulometry was used, with grain diameter between 0.2 mm to 0.6 mm. The sand is siliceous, basically composed of quartz (SiO_2). For this research a Calcitic Hydrated Air Lime, labelled CL, was used.

The lime for construction in Brazil are classified by different levels of purity, and this lime is classificated as CH-I (ABNT, 2003). According to the manufacturer (ICAL), this lime stands out for not containing unhydrated oxides in its composition. Due to the high concentration of calcium and magnesium hydroxides, CH-I hydrated lime has a high binding capacity and low water holding capacity. The cow dung used, labeled CD, was collected in the rural area of Itabirito, Minas Gerais. The cows were basically fed on pasture, and therefore had enough vegetable fibers in their excrement. Traditionally in the region, residents collect the fresh excrement in the corral and pile it in the shade to “cure” it. In this process, heat, water, methane, carbon dioxide and ammonia are released (Bamogo *et al.,* 2013). Daily the excrement is turned over for two weeks to aerate and cool the pile. At the end of 2 to 3 weeks, there is a dry material, which a mild odor and with no clod. According to Millogo et al. (2016), when fresh, the cow dung contains 80 to 90% water in mass. After drying, the main components are vegetable fibers (essentially composed of cellulose, hemicelluloses and lignin) and organic amine compounds (from ammonia that evaporated on drying shade). Also there is potassium, phosphoric acid and traces of quartz and clay ingested by the animal accidentally along with the grass. In the laboratory, the cow dung was manually broken down and passed through a 2.79 mm sieve to retain the remains of thin branches, leaves and animal hair. After being sieved, the material became very homogeneous and full of vegetable fibers whose length does not exceed 2 cm (Figure 1).

Figure 1. Cow Dung“cured”, dry andseived

The mineralogical characterization of the earth was performed with a X-ray diffractometer (XRD) for powder samples PHILLIPS (PANALYTICAL), with X'Pert-APD system, PW 3710/31 controller, PW 1830/40 generator and PW 3020/00 goniometer. A semi-quantitative chemical analysis was also performed using a sequential X-ray fluorescence (XRF) spectrometer PHILLIPS (PANALYTICAL) model PW-2400.
The particle size distribution of KCE was analysed by dry sieving and sedimentation, according to standards EN 1015-1 (CEN, 1998a) and NBR 7181 (ABNT, 2016b). The particle size distribuition test of sand was not performed because it is already especified on the manufacturer packaging (PURA SÍLICA). Using the NBR 6459 (ABNT, 2017) and NBR 7180 (ABNT, 2016a) standards, the Liquid Limit, Plasticity Index and hygroscopic humidity of the Kaolinitic earth was also assessed.

Mortars and Samples: To achieve the objective of this work, five mortars were formulated. One of which is a reference mortar and the other four have the following additions: 5% of air lime, labelled KCE-5CL; 10% of cow dung, labelled KCE-10CD; 20% of cow dung, labelled KCE-20CD; and a blend of 5% ar lime with 10% of cow dung, labelled KCE-5CL+10CD.
To define the mortar formulations and the necessary sand adition that allow to achieve mortars with limited shrinkage, a preliminary shrinkage test was performed by observation of the cracks occurring at the surface of a plastered masonry block (Figure 2). The preliminary shrinkage test shows that is necessary to add 4 parts of additional sand to 1 of earth. Therefore, all the formulated five mortars have in common the proportion of KCE: Sand (1: 4) in their composition (Table 1).

Figure 2. Preliminary shrinkage testwith grative sand addition (KCE: sand)

The mortars were produced using an electrical equipment for mechanical mixing following the instructions of the DIN 18947 (DIN, 2018). The fresh mortars were characterized by the flow table consistency, using the test procedures described in standard EN 1015-3 (CEN, 1999a), and the wet density, according to EN 1015-6 (CEN, 1998b). A different material to be evaluated as a stabilizer and a different quantity of water, was added in each mortar formulation to obtain a 175 mm flow table consistency (DIN, 2018). In addition, all fresh mortars had a density greater than 1.2 kg/dm³ (Table 1), as required by the DIN standard.

Table 1. Mortars designation, composition in mass, including water necessary to achieve 175mm flow table consistency, and wet density

Mortar's Samples		Earth:Sand		Stabilizer Adition		Water Adition (%)	Mortar Fresh State Density (g-cm³)
		Earth (%)	Sand (%)	Hydrated Lime (%)	Cow Dung (%)		
KCE:Sand (1:4)	KCE-REF	20	80	-	-	15	1,88
	KCE-5CL	20	80	5	-	16	1,81
	KCE-5CL+10CD	20	80	5	10	24	1,74
	KCE-10CD	20	80	-	10	24	1,59
	KCE-20CD	20	80	-	20	30	1,47

To perform the tests, two types of samples were produced with each formulated mortar: 4 prismatic samples with 16 cm x 4 cm x 4 cm for linear shrinkage, dry density, flexural and compressive strength tests; 2 samples of plaster on a substrate for the adhesion test, 1 on adobe and 1 on ceramic brick, so that the influence of the substrate could be assessed, all plastered on a largest face (30 cm x 20 cm) with a thickness of 1.5 cm. The samples were produced and stored in the laboratory, at 63% relative humidity (RH) and 26□C (Figure 3). The samples remained in the laboratory environment from their production until the tests were carried out. All samples were tested between the ages of 50 and 60 days, after reaching a constant mass and to provide time enough for the hydrated lime carbonation process.

Mortar Test methods: To assess the Linear Drying Shrinkage, three prismatic samples were used according to the guidelines of standard DIN 18947 (DIN, 2018). To assess the Dry Bulk Density the same three prismatic samples were used, according the EN 1015-10 (CEN, 1999b). The Adhesive Strength was assessed with the samples of plasters on the blocks (adobe and brick) and the according to EN 1015-12 (CEN, 2000). To perform the test, a DYNA Z16 - Pull-off Tester (PROCEQ) equipment and a structural adhesive based on epoxy resin were used. To determinate the flexural and compressive strength, the standard EN 1015-11 (CEN, 1999c) was followed. Firstly, the flexion test was performed, breaking 3 samples per formulation. Then, with the 6 halves obtained, the axial compression test was performed. For both tests, an Universal Testing Machine SHIMADZU, model AGS-X 300 kN, was used. For the flexion test, a 5 kN load cell was coupled and configured at a constant speed of 0,2 mm/min on a vertical load application. For the compression test, the 5 kN load cell was maintained and the speed was set to 0,7 mm/min.

RESULTS AND DISCUSSION

Materials characterization: The mineralogical characterizationresults is presented in Table 2. It shows that the earth presents predominance of Kaolinite Al2Si2O5(OH)4, followed by Quartz SiO2. There are also, at lower values, the presence of Goethite: FeO (OH), Moscovite: KAl2Si3AlO10 (OH)2 and Microcline: KAlSi3O8. The particle size distribution is presented in Figure 3.

The granulometric characterization results revealed that the earth presents in its composition 70% of the clay fraction, 15% of the sand fraction and 15% of the silt fraction. With this results also is possible to afirm that after adding four parts of additional sand to one part of KCE earth, the final granulometric composition of all 5 formulatted mortars is 14% of Kaolinitic clay, 3% of silt and 83% of sand. More water and stabilizer adittion. Also was determined that KCE has Liquidity Limit LL= 54%, Plasticity Index IP= 23% and hygroscopic humidity of 14%.

The Kaolinitic Clayish Earth (KCE) density is d=1,06g/cm³.The medium sand density is d=1,38 g/cm³.The CH-I density is d=0,56 g/cm³. The cow dung density is d=0,38 g/cm².

Table 2. Mineralogical characterization of KCE

Kaolinitic Clayish Earth
XRF (Am20-020) – elements present:
Al, Si, Fe, O (high);
Ti, Mn, Cr, P (low);
K, S, Mg, Cl, Ni, Zr, Cu (traces).
XRD (Am19-4220) – minerals (phases) presents:
Kaolinite (abundant);
Quartz (abundant);
Muscovite (low);
Microcline (low);
Goethite (low);
Rutile (trace).

Flow table and wet density: To achieve a flow table consistency of 175 cm, there is a tendency of kneading water increase with the addition of stabilizers. With the addition of stabilizers the wet density decreases (Table 1).

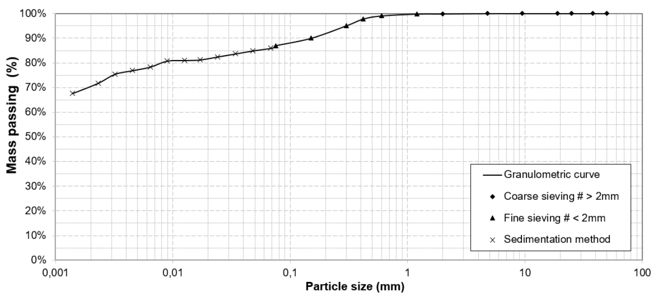

Figure 3. Granulometric distribution of KCE

Linear drying shrinkage: On the linear shrinkage test, all mortars comply the DIN 18947 (DIN, 2018) requirements, with a shrinkage index below 2% (Figure 5). Also is possible to note the cow dung additions alone seem to be more efficient to reduce the shrinkage on earth mortars than the addition of air lime together with cow dung.

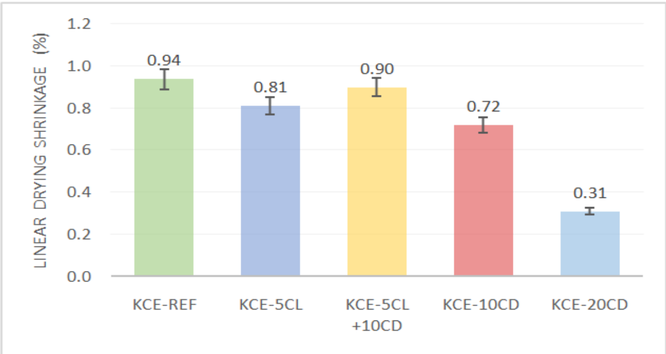

Figure 4. Linear drying shrinkage of earthen mortars with air lime (CL) and cow dung (CD) additions: average and standard deviation

Apparent Dry bulk density: The dry bulk density of all mortars have classifiable values regarding the parameters presented by DIN 18947 (DIN, 2018) (Figure 6). The reference mortar KCEE-REF and the mortar with 5% of air lime (KCE-5CL) are 1.6 class; the mortars with both lime and cow dung (KCE-5CL+10CD) is 1.4 class; the mortars with 10% and 20% cow dung (KCE-10CD and KCE-20CD) are 1.2 and 1.0 classes, respectively.

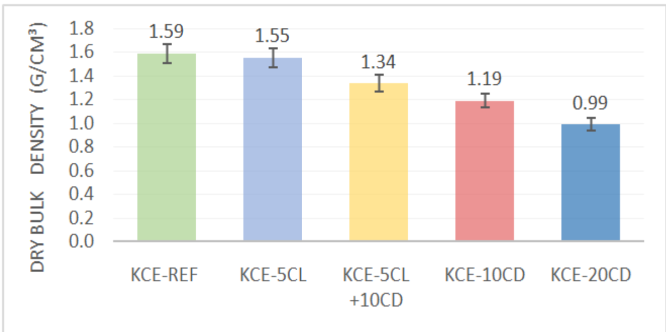

Figure 5. Dry bulk density of earthen mortars with air lime (CL) and cow dung (CD) additions: average and standard deviation

Flexural, compressive and adhesive strength: Regarding the results of the mechanical strength tests (Figure 7), the reference mortar (KCE-REF), without stablizers, has the minimum flexural strength (Fs) value classifiable by DIN standard, Fs = 0.3 MPa. The addition of lime increased by 10% the Fs and the addition of 10% cow dung increased it by 60%. The simultaneous addition of these two materials increased by 33% and the addition of 20% cow dung reduce by 17% the flexural strength of the reference mortar.

On the compressive strength (Cs) test, any mortar reached Cs = 1.0 MPa, so none of them could be classified by the DIN standard. However, all mortars could be classified as general plastering mortars by the EN 998-1 (CEN, 2016) because they all meet the minimum limit of 0.4 MPa. According to Röhlen and Ziegert (2011), earth mortars generally have values for compressive strength between 0,6 and 3 MPa. Only the mortar with 20% of cow dung presents an inferior value. The reference mortar showed Cs= 0.6 MPa. The addition of 5% hydrated air lime reduce the compressive strength by 5% but the addition of 10% cow dung, increase by 45%. The combined addition of lime and cow dung increase by 17% and the addition of 20% cow dung reduce by 17%.

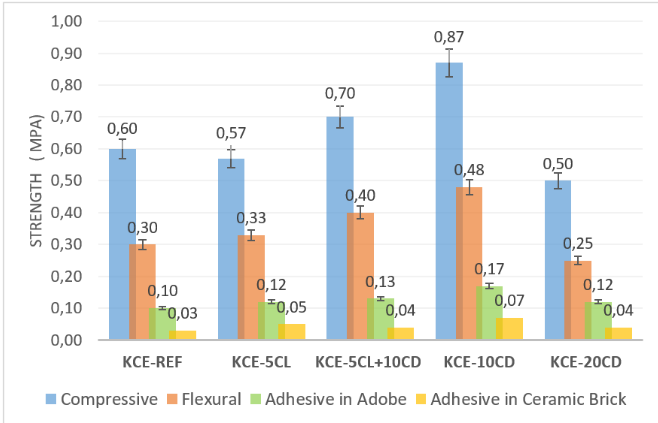

Figure 6. Compressive, flexural and adhesive strengths on adobe and brick of earthen mortars with air lime (CL) and cow dung (CD) additions: average and standard deviation.

The adhesve strength (As) was realized on two suports, adobe and ceramic brick. On ceramic bricks, only KCE-5CL and KCE-10CD reached the minimum value indicated in the DIN (2018) standard, As= 0.05 MPa. In relation to KCE-REF (As= 0,03 MPa), KCE-5CL increased the adhesive strength by 67% and KCE-10CD increased by 133%. But when applied on adobe, all ratios showed results classifiable by the DIN (2018) standard. Regarding KCE-REF (As= 0.10 MPa), KCE-10CD increase the adhesive strength by 70%, while KCE-5CL and KCE-20CD increased by 20%, and KCE-5CL+10CD increased by 30%. The results show the addition of 5% air lime slightly reduced the compressive strength in relation to the reference mortar KCE-REF, while slightly increased for flexural and adhesive strength on both substrates. As observed in Gomes *et al.* (2018) for another kaolinitic earth, this occurs because the feable structure matrix created by the calcium carbonate interrupts the connections between the clay sheets, damaging the clayish structural matrix. And because the addition of lime is low (5%), the lime does not form a structural matrix strong enough, resulting in a reduction in the compressive strength of the mortar. However, Faria (2018) presents that earth mortars with more than 20% of air limecan increase the mechanical strength of mortars. The results also show that in comparation with the addition of 5% lime, the addition of 10% cow dung and the combo adittion (KCE-5CL+10CD) shows superior performance in all the evaluated tests. According to Bamogo *et al.* (2020) the vegetable fibers present in the cow dung and the insoluble silicate amines formed are responsible for the effects caused by this addition on earth mortars. The researchers justify that the insoluble silicate amines ($Si(OH)_4 4NH_3$) are formed in the reaction of the ammonia compounds present in cow dung with the fine quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$) presente in the soil.

Bamogo *et al.* (2020) evaluated the additions of 2, 4 and 6% by weight of cow dung in the mixture of earth mortars. The researchers show that the positive effects caused by cow dung increase with increase the addition of this material. Increasing the proportion of additions, Vilane (2010) evaluated the additions in mass of 5, 10, 15 and 20% of cow dung in the earth mass for producing earth blocks (adobe). The results indicated the addition of 10% cow dung got the best performance in relation to mechanical strength and water absorption. Similarly toVilane (2010), the results of the present research also show the volumetric addition of 10% cow dung as more advantageous than 20%, for the KCE earth mortars. On the other hand, the simultaneous addition of 10% cow dung and 5% lime, worsened the performance of the mortar in relation to the same additions separately, but its still improved the performance in relation to the reference mortar in all tests performed. For this reason, for KCE, lime and cow dung seem to be more efficient when used separately. It is interesting to observe how the shrinkage on KCE mortars is directly related with the performance of the mechanical strength and adhesion of mortars. Although not visible, the mortar with the lowest shrinkage should present fewer microcracks in the plaster and offer an improved contact surface and, therefore, better adhesion to the substrate, as well as greater mechanical resistance.

Conclusion

The kaolinitic reference mortar, without stabilizing additions, is a mortar that presents satisfactory performance in all tests. But the stabilizing additions provided some improvements. The addition of 5% of air lime reduced linear shrinkage by 14%, reduced compressive strength by 5%, increased flexural strength by 10% and increased adhesive strength on adobe by 20%. The addition of 10% of cow dung,exceeded the addition of lime in all tests, evidencing the quality of the traditional vernacular method of stabilizing earth mortars. In fact, the mortar with 10% cow dung increased compressive strength by 45%, flexural strength by 60% and adhesive strength by 133%, making it a very efficient addition to earth plasters. This mortar presented improved characteristics when compared to a mortar with both air lime and cow dung. The properties of adding cow dung as a stabilizer on earth mortars have also been evaluated by other researchers. These publications also conclude that the addition of cow dung reduces shrinkage and increases the mechanical strength. However, no publications were found that compared the effects of adding cow dung with the addition of lime, and the effect of a blended addition of air lime and cow dung, for the same earth to get a sense of the performance of this material compared to a stabilizer binder already established in the literature. Therefore, the present study leaves its contribution to the field of research of cow dung as aconstruction material with great potential for the stabilization of earthen mortars. Further research will analyse the effect of these stabilizers on mortars durability.

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