

# The compatibility of earth-based repair mortars with rammed earth substrates

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## Abstract

Earth constructions are susceptible to degradation due to natural or human causes. The degradation of the exterior surface of earth walls is very common, either due to lack of maintenance or to the use of incompatible materials, and often requires the application of a repair mortar.

This work analyses experimentally the performance of earth-based repair mortars applied on rammed earth surfaces. The mortars are based on earth collected from rammed earth buildings in south Portugal or on a commercial earth. Eight repair mortars were formulated, with the unstabilized soils or including also small binder content. Four types of binder were tested: hydrated air-lime, natural hydraulic lime, Portland cement and natural cement.

The repair mortars were applied on two types of standard defects purposely made on rammed earth blocks, representing the most currently defects found on exterior rammed earth surfaces: standard superficial defect and standard deep defect. The performance of the mortars, their compatibility with the substrates and the visual effectiveness of the intervention were evaluated.

It was concluded that the mortars behaved differently when applied on different rammed earth supports. However, the best performances occurred always for the mortars made from unstabilized soil identical to that of the rammed earth substrate. Indeed, the use of stabilizers systematically worsened the behavior of the repair mortars, regardless of the type of binder used for that purpose.

**Keywords:** rammed earth substrates, earth repair mortars, compatibility between materials

## 1. Introduction

In a society where questions related with sustainable development and ecology start to matter, the use of locally sourced, non-processed building materials, such as natural earth, is a possible path for a greener economy. Other advantages of earth as a building material are its abundance, low cost and ease of recycling.

In Portugal, the number of new rammed earth constructions is increasing, as it is also the number of old rammed earth building being rehabilitated for modern uses. The degradation of the exterior surface of earthen walls is very common, either due to a lack of maintenance which eventually conducts to direct exposition to the environment, or to the application of incompatible renders or other materials. Restoring the functionality and aesthetics of these walls often requires the application of a repair mortar.

Aiming at the development of appropriate repair mortars for rammed earth constructions, eight repair mortars were produced with four types of soil and tested on three types of rammed earth substrates. This study is important, insofar as the authors are not aware of other studies in which earth mortars are applied to a substrate, allowing a direct assessment of the compatibility between them. The substrates consisted of rammed earth blocks manufactured in the lab for that purpose with soil collected from old rammed earth buildings. Standard defects - superficial irregularity and deep voids - were created on the surface of these blocks, representing those commonly found in the exterior surfaces of rammed earth walls (Gomes and Faria 2011). The eight repair mortars were based on either the same earth as the substrate or a commercial

earth. The commercial earth was used in its natural state or after stabilization with low contents of hydrated air-lime, natural hydraulic lime, Portland cement or natural cement.

The earth-based mortars were applied on two types of standard defects - standard superficial defect and standard deep defect - in order to evaluate its behaviour as repair mortars. The repair of deep defects was made by two different ways - the voids were filled only with mortar or also with coarse gravel to reduce the mortar's thickness.

The present article describes and discusses this work which is part of a more general effort that included artificial ageing tests to assess the adequacy of earth-based mortars as repair mortars for rammed earth materials.

## 2. Materials

Four types of earth were used in this study. Three of them (earths Av, PD and VC) were collected from non deteriorated parts of walls of unstabilized rammed earth buildings located in Alentejo region, south Portugal. These three earths were chosen because they represented different grain size distributions and types of clay. Av is more sandy than PD and VC, that are more clayey. The fourth (earth RE) is a commercial earth, composed mainly of clay. The four materials are fully characterized elsewhere (Gomes *et al.* 2012a, Gomes *et al.* 2012b).

The uniformity of the particle size distribution (PSD) is an important aspect. A uniform PSD allows a more efficient compaction because the grains can find an arrangement that minimizes empty spaces between them (Keable 1996; Walker *et al.* 2005). It is commonly accepted that a more compact material results, in principle, in lower porosity and higher mechanical resistance, hence, higher durability (Keable 1996; Walker and Australia 2001; Walker *et al.* 2005). Morton (2004) also refers that buildings with earthen well-graded materials can be remarkably durable, while poorly graded mixes will never perform well.

### 2.1 Rammed earth blocks

The rammed earth blocks were produced with the site-collected earths Av, PD, and VC. The preparation of the material is detailed in Gomes *et al.* (2012c). It was first disaggregated with a rubber hammer (not to break the aggregates) and then dry sieved, rejecting the material that passed through the sieve 12.5 mm (# 1/2" ASTM).

### 2.2 Mortars

The compositions of the eight repair mortars are presented in Table 1. As seen, the mortars with clayish earths include sand. The sand is composed mainly by quartz and has grain dimension in the range 0.6 to 2.0 mm. Its addition had the main objective of reducing the shrinkage of the mortar which otherwise would be very high due to the clay content of the earths. The MRE mortars include also 15% of powder hydrated air-lime (AL), natural hydraulic lime (NHL), Portland cement (PC) or natural cement (NC).

The earth was prepared as follows: (i) the three earths (Av, PD, VC) collected from the buildings were wet sieved through a 2 mm sieve (Nº. 10 ASTM); the material that passed in the sieve, after decanting, was dried in a ventilated oven at 40 °C; it was grinded and homogenized; (ii) the commercial earth (RE) was grinded to disaggregate the material and then the sample was homogenized.

Figure 1 shows the particle-size distribution of the unstabilized materials for the mortars, MAV, MPD, MVC and MRE.

To fill some of the standard deep defect coarse gravel with dimensions between 20 and 40 mm was also used to reduce the mortar thickness.

Table 1: Composition of the eighth mortars

Group of earth based mortars	Designation of the mortar	Weight proportions (clay:sand)	Volumetric proportion (clay:sand)	Stabilizant (%)*			
				AL <sup>(1)</sup>	NHL <sup>(2)</sup>	PC <sup>(3)</sup>	NC
Local earth Av	MAv	1:0	1:0	-	-	-	-
Local earth PD	MPD	1:1,9	1:1,5	-	-	-	-
Local earth VC	MVC	1:2,4		-	-	-	-
Reference-earth	MRE			-	-	-	-
Reference-earth with hydrated air-lime	MRE_AL15			15	-	-	-
Reference-earth with natural hydraulic lime	MRE_NHL15	1:3,8	1:3	-	15	-	-
Reference-earth with Portland cement	MRE_PC15			-	-	15	-
Reference-earth with natural cement	MRE_NC15			-	-	-	15

\* Percentages by weight in relation to the reference earth.

<sup>(1)</sup> EN 459-1 CL 90-S; <sup>(2)</sup> EN 459-1 NHL5 and <sup>(3)</sup> CEM II/BL 32.5 N.

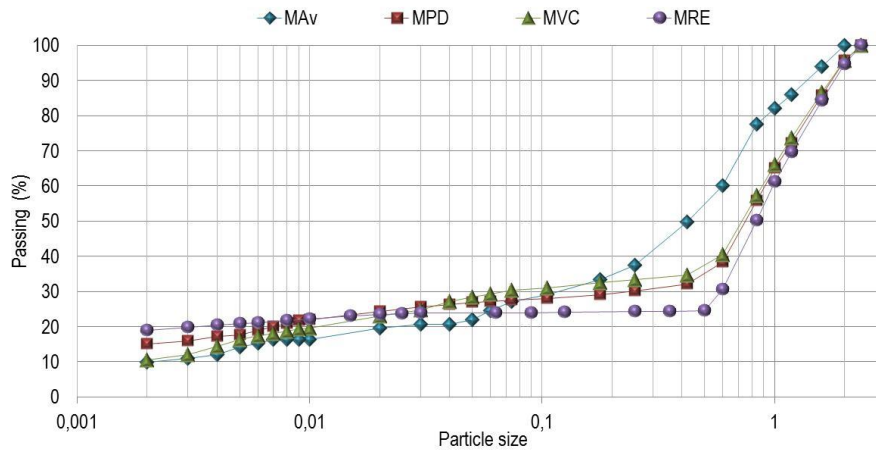


Figure 1: Particle size distribution of the mortar materials, MAv, MPD, MVC and MRE

### 3. Experimental methodology

#### 3.1 Rammed earth blocks

Ten rammed earth blocks, with dimensions 30cm×20cm×28cm, were manufactured with each type of collected earth (BAv, BPD and BVC). The two types of current defects were recreated on the blocks: superficial loss of material (2 cm depth) and deep voids (semi sphere with 10 cm diameter). The blocks were kept in a controlled environment at 20°C and 50% RH for 20 months. Details of their manufacturing procedure can be found in Gomes *et al.* (2012c).

#### 3.2 Preparation and characterization of the earth-based mortars

For the mixing of the mortars, EN 196-1 was followed as closely as possible. A mechanical mixer was used composed by a vat of stainless steel with a capacity of 3 liters and a paddle mixer driven by an electric motor.

The methodology used for mortars MAV, MPD and MVC was as follows: (i) manual homogenization of the material; (ii) introduction of water into the mixer, followed by introduction of the dry material; (iii) mixing at low speed for 90 seconds; (iv) a 90 second halt (in the first 15 seconds the adhering mortar was removed from the walls of the vat with a rubber spatula and added to the remainder mortar); (v) mixing at low speed for another 60 seconds.

For the MRE mortar it was necessary to increase the mixing time because otherwise a good homogenization would not be achieved due to the large clay content. Thus, after (ii) the mortar was manually mixed for an extra period of 2 minutes. Also, the mechanical mixing referred in (iii) was prolonged to 150 seconds.

The consistence by flow table, EN 1015-3 (Table 2), was used to determine the amount of water in the mortars. The quantity of water was added so that the flow values were adjusted to the target 160-176 mm interval which corresponds to earth-based mortars with excellent workability (Gomes et al 2012c).

It was also important to limit the shrinkage of the mortars (Gomes et al 2012c). The linear shrinkage of raw earth materials is commonly evaluated by Alcock's test (also called shrink-box test). Linear shrinkage should not be more than 3% in accordance with the standard New Zealand (SNZ 4298, 1998). Interestingly, linear shrinkage does not appear to be representative of total shrinkage; because of this fact volumetric shrinkage was also determined (Gomes *et al.* 2012a, Gomes *et al.* 2012b).

Table 2: Water/dry material ratio, flow table consistency, linear and volumetric shrinkage of the eight earth-based mortars

Mortar designation	Water/dry material ratio	Flow (mm)	Shrinkage (%)	
			Linear	Volumetric
MAV	0,13	174	≈0	≈0
MPD	0,20	177	1,00 ± 0,18	1,25 ± 0,23
MVC	0,21	177	1,35 ± 0,36	1,46 ± 0,15
MRE	0,31	170	0,90 ± 0,12	0,95 ± 0,08
MRE_AL15	0,30	170	1,36 ± 0,31	6,21 ± 0,27
MRE_NHL15	0,29	172	0,57 ± 0,38	5,49 ± 0,50
MRE_PC15	0,29	180	0,37 ± 0,06	3,19 ± 1,00
MRE_NC15	0,29	159	1,72 ± 0,06	6,11 ± 0,54

### 3.3 Application technique of the repair mortars

The three mortars MAV, MPD e MVC that correspond to local earths were applied only in the blocks made from the same earth. Differently, the commercial earth mortars (MRE) are intended for general use and, therefore, were applied on the three types of rammed earth blocks. For each mortar three applications were always carried out, either to the standard superficial defect or for each type of deep defect filling.

Before applying the mortars the rammed earth surfaces were prepared as follows:

- (i) the repair area was brushed to remove loose particles and dust;
- (ii) the surface was wet by spray 30 min, 20 min, 10 min and 30 sec before applying the mortar to avoid a sudden drying of the mortar, thereby preventing a large initial retraction.

The application technique of the repair mortars in the superficial was the following (Figure 2):

- (i) the mortar was thrown vigorously against the support with a trowel, always from the bottom to the top;
- (ii) the mortar was tightened and repointing was made particularly at the corners, with a trowel;
- (iii) the surface of the mortar was regularized with a wooden or metal ruler;
- (iv) the surface of the mortar was smoothed with a sponge.



Figure 2: Application of the mortar MRE\_AL15 on a standard superficial defect of the PD rammed earth

In the case of the deep defects the mortar was applied by the following procedure (Figure 3):

- (i) the mortar was launched vigorously against the support with a trowel followed by tightening; the thickness of this first mortar layer was of 0.5 to 1 cm;
- (ii) in the case of using coarse gravel to partially fill the holes of the defects these were applied after this first layer of mortar;
- (iii) the interval of 15-20 min between the application of mortars layers was respected so that the previous layer had time to achieve enough resistance;
- (iv) the application of the last layer of mortar was careful, especially in the zone of connection with the support and the repointing should be carried out, if necessary;
- (v) the surface was regularized with a wooden or metal ruler;
- (vi) finally the surface was smoothed with a sponge.

Immediately after application of the mortar begins the initial drying shrinkage, which is inhibited by adhesion to the support. This shrinkage leads to the development of shear stresses in the plane of contact of the mortar with the support. This can cause the detachment and tensile stresses in the mortar which can cause cracking. Because of this it was necessary to repoint some cracks. Cracks appeared in the mortars approximately 2 to 3 hours after application, on both types of standard defects and on both types of deep holes (with and without coarse gravel). The repointing was undertaken 4 hours after application.



Figure 3: Application of the mortar MRE on a standard deep voids defect of the Av rammed earth

## 4. Results and discussion

The performance of the repair mortars was evaluated in fresh state in terms of workability and all the mortars were with good workability. When hardened, the mortars were evaluated 10, 30 and 90 days after their application on the blocks. However, no changes were detected between the 10 and 90 days, which means that most of the shrinkage occurred before that.

Tables 3 and 4 summarize the observed anomalies which were: micro cracks; medium cracks, large cracks, and loss of adhesion between the mortar and the support - rammed earth blocks BAv, BPD and BVC. The classification of cracking in the mortar was only based on the respective opening, adopting the French standard NF P 84-401 (Veiga 1998), being this specific for stabilized renders and plasters: micro cracks, width less than 0.2 mm; medium cracks, width between 0.2 and 2 mm; large cracks, width greater than 2 mm.

Table 3: Main decay patterns of the repair mortars applied on the standard superficial defect

	BAv	BPD	BVC
MAv	micro cracks <sup>(1)</sup>	-	-
MPD	-	micro + medium cracks <sup>(1)</sup>	-
MVC	-	-	micro <sup>(1)</sup> cracks
MRE	medium cracks	medium cracks <sup>(2)</sup>	micro <sup>(1)</sup> + medium cracks
MRE_AL15	micro + medium cracks loss of adhesion	medium cracks	micro + medium <sup>(2)</sup> cracks
MRE_NHL15	micro + medium cracks	micro + medium cracks <sup>(2)</sup>	micro + medium cracks <sup>(2)</sup>
MRE_PC15	medium cracks loss of adhesion	medium cracks <sup>(2)</sup>	medium cracks
MRE_NC15	micro + large cracks <sup>(2)</sup> loss of adhesion	micro + medium cracks	micro + medium cracks <sup>(2)</sup>

(1) only contour cracks

(2) cracks only in the mortar

Table 4: Main decay patterns of the repair mortars applied on the standard deep defect

	BAv	BPD	BVC
MAv	medium cracks <sup>(1)</sup>	-	-
MPD	-	micro + medium cracks <sup>(1)</sup>	-
MVC	-	-	micro + medium cracks <sup>(1)</sup>
MRE	micro <sup>(2)</sup> + medium cracks <sup>(1)</sup>	not visible	micro <sup>(1)</sup> + medium cracks <sup>(2)</sup>
MRE_AL15	micro + medium cracks <sup>(1)</sup>	micro <sup>(1)</sup> + medium cracks	micro <sup>(1)</sup> + medium cracks
MRE_NHL15	medium cracks <sup>(1)</sup>	micro <sup>(2)</sup> + medium cracks <sup>(1)</sup>	micro <sup>(2)</sup> + medium cracks
MRE_PC15	medium cracks <sup>(1)</sup>	medium cracks	medium cracks
MRE_NC15	medium cracks <sup>(1)</sup> loss of adhesion	micro <sup>(2)</sup> + medium cracks <sup>(1)</sup>	micro <sup>(2)</sup> + medium <sup>(1)</sup> + large <sup>(2)</sup> cracks

(1) only contour cracks

(2) cracks only in the mortar

Analyzing the anomalies observed for the eight families of mortars (Tables 3 and 4), it is seen that:

- (i) the unstabilized mortars MAv, MPD and MVC applied on blocks of the same type of earth showed the best performance, presenting just contour cracks;
- (ii) the performance of the stabilized MRE-based mortars (Figure 4) was always worse than that of the unstabilized MRE mortars: cracking was more intense and sometimes was accompanied by detachment of the repair mortar;
- (iii) loss of adhesion between the mortar and the support was verified only for the Av substrate which has low clay content;

- (iv) the incorporation of gravel did not prevent or reduce the occurrence of anomalies in the mortars applied on the deep standart defect.

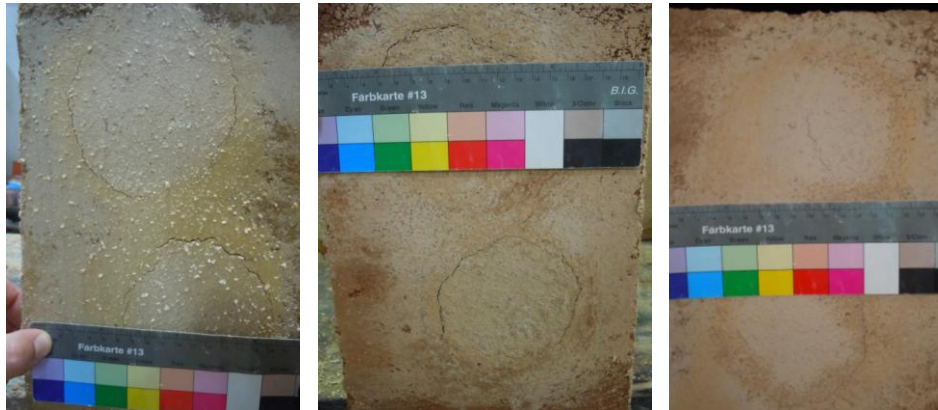


Figure 4: Medium cracks on the mortar MRE\_AL15 applied on the standard deep voids defect in the blocks: left, in BAV; center, in BPD; and right, in BVC

Unstabilised mortars had only few cracks and did not detached from the substrate. This should be due to their lower drying shrinkage (Table 2) and to the fact that they have mechanical characteristics closest to those of the substrate. The similarity between the mortar and the substrate is particularly relevant for the MAV, MPD and MVC mortars which were applied on blocks of the same type of earth and, in fact, were the ones with better behaviour. This assertion is also corroborated by Morton (2004), which refers that compatibility of materials is an important criterion. He also refer that constructions are more vulnerable to progressive decay at the interface of different materials, e.g. when in the surface is applied other denser materials.

The stabilized mortars behaved worse, particularly in the case of the BAV substrate where detachment of the whole repair occurred in several cases (Figure 5). This was probably due to the lower adesion provided by this relatively high sand content substrate.

These results validate that in practice, it will be more appropriate to repair unstabilized rammed earth walls by means of unstabilized mortars, preferably based on earth similar to that of the substrate. They are also philosophically more defensible conforming to the principle of like for like materials replacement by BS 7913 (1998). "A traditional craft-based approach to repair, replacing decayed material on a like for like basis is preferred" (BS 7913, 1998, p.10). The repair philosophy must be the "minimum intervention to ensure long-term stability and optimum performance of the structure without causing physical disruption" (Maniatidis and Walker 2003, p.72).

On the deep standart defect, the incorporation of coarse gravel did not improve the performance of the repair mortars. However, it facilitated their application because it decreased the amount of mortar used. It also made the application quicker because the repair was achieved with fewer mortar coats.



Figure 5: Mortar MRE\_NC15 applied in block BA<sub>v</sub> on standard superficial defect: left, detachment of the mortar; center, cracks; and right, detail of large cracks

## 5. Conclusions

Mortars behaved differently when applied on different rammed earth supports. The best performance occurred in the mortars that were composed of unstabilized soil that was identical to the rammed earth substrate. As the repair is made to reinstate the wall thickness and is probably, when micro and medium cracks appear they can be easily covered when the wall surface is protected by a rendering or a plastering system. As the repair is made to reinstate the wall thickness and is probably, when micro and medium cracks appear they can be easily covered when the wall surface is protected by a rendering or a plastering system.

The use of low amounts of the binders acting as stabiliser systematically worsened the behavior of the repair mortars, regardless of the type of binder. This indicates that in practice, it will be more appropriate to repair unstabilized rammed earth walls by means of unstabilized mortars, preferably based on earth similar to that of the wall itself. This also has additional conservation benefits as it enables the repair of the structure on a like for like materials basis.

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