Experimental Study of the Effects of Charcoal and Crushed Bricks on the Air Lime Mortars Properties

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Abstract: ***The lime gathers all the qualities, required from building materials within the framework of the sustainable development (Low grey energy and absorption of CO2 during the hardening. However, lime presents certain disadvantages like relatively slow setting and carbonation, low mechanical performances compared with cement and high drying shrinkage. For this study, the charcoal and the crushed bricks were added with different proportions to the lime mortar in order to assess the impact on the physical and mechanical properties of this mortar. The primary focus was to assess the differences in setting time and investigate the reasons behind the measured differences. In parallel, the mortar prisms 4 × 4 × 16 cm was analyzed in the laboratory conditions in view of mechanical properties and shrinkage phenomena. Finally, a RILEM Test Method II.4 is used to measure water absorption under low pressure and permeability to water of the lime mortar.***

Keywords: Air lime mortar; setting time; charcoal; crushed bricks; physical-mechanical properties

1. Introduction

The limitation of energy consumption necessary for the manufacturing, for the maintenance, for the adaptation and for the demolition of buildings, what we call grey energy, becomes very important so it is very necessary today to deal with this subject and to see where and how it is recommended to act [4].

In order to improve the qualities of the air lime mortar, it was thought to add charcoal Figure 1 and crushed bricks Figure 2 as it were customary among the Romans in ancient times [1] [6].

Of this reason and as the lime have all the qualities which we have to require from a material of construction within the framework of the sustainable development (Low grey energy and absorption of CO2 during its hardening) where from the idea to formulate a mortar with this binder. However, lime presents certain disadvantages like relatively slow hardening and carbonation, low mechanical performances compared with cement and high drying shrinkage [3].

In order to improve the qualities of the air lime mortar, it was thought to add charcoal and crushed bricks as it were customary among the Romans in ancient times [1] [6].

The objective of this work is to study the effects of adding charcoal and crushed bricks on the matrix of aerial lime mortar in order to improve setting time, permeability, and mechanical behavior due to these additions.

2. Mortar Composition

For this study, the charcoal and the crushed bricks were added with different proportions [1]. Two formulations are studied to estimate the variation of setting time of a lime mortar with charcoal**.**

2.1. Specimen designations

- 1L+1S+N%Ch: 1Volume of Lime + 1Volume of Sand +N% of Charcoal.
- 1L+2S+N%Ch: 1Volume of Lime + 2Volume of Sand +N% of Charcoal.
- 1L+1/2S+1/2CB +N%Ch: 1Volume of Lime + 1/2Volume of Sand +1/2Volume of Crushed Bricks +N% of Charcoal.
- N%Ch: Refers to the dosage of charcoal.
- d (mm): Penetration of Vicat Test.

Figure 1: Charcoal

Figure 2: Crushed Bricks

3. The Vicat Test

3.1 Title and authors

The VICAT test mold undergoes shrinkage, which means that the end of setting is not characterized by a value of "d" = 40 mm. The value of "d" is variable and for this reason "d" = 35 mm is considered as the reference value for this study Figure 3.

Figure 3: VICAT test mold

3.2. First stage: Introduction of charcoal and choice of sand volume

This first selective stage included the VICAT tests of mortars with two volumes of sand and one volume of lime and mortars with one volume of sand and one volume of lime.

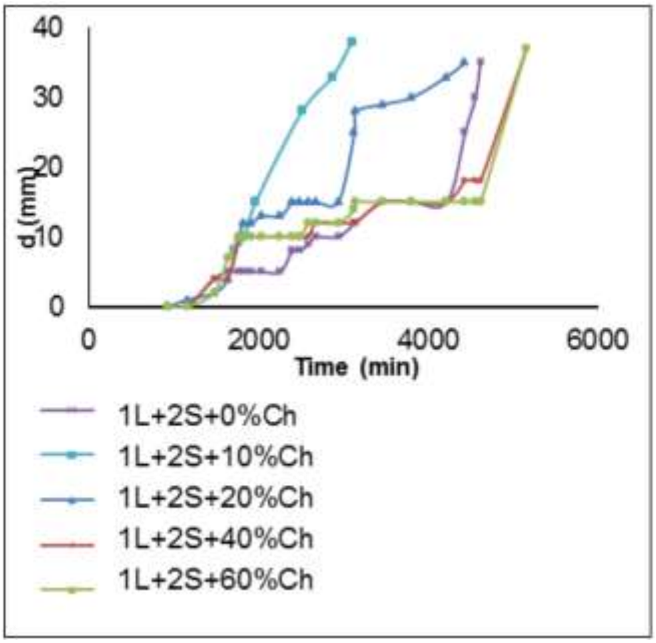

Figure 4: The variation of "d" with time of mortars with 1 Volume of Lime + 2 Volume of Sand + n% of Charcoal

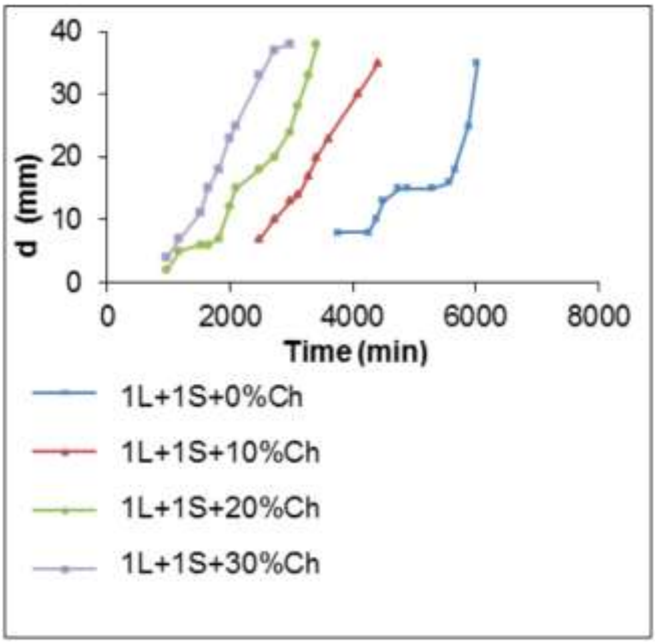

Figure 5: The variation of "d" with time of mortars with 1 Volume of Lime + 1 Volume of Sand + n% of Charcoal

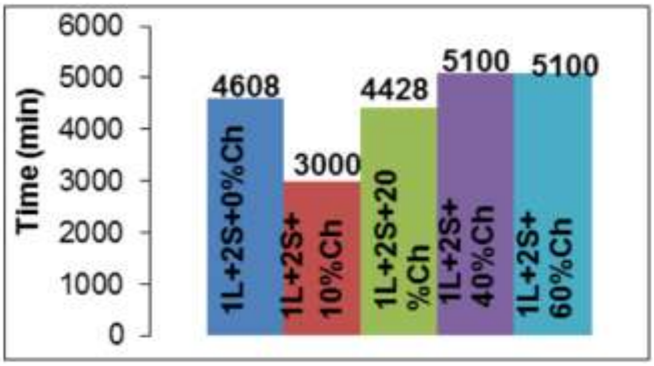

Figure 6: Final setting time of mortars with 1 Volume of Lime + 2 Volume of Sand + n% of Charcoal

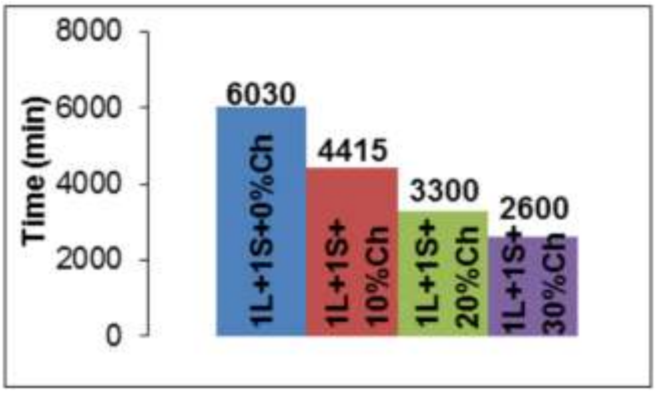

Figure 7: Final setting time of mortars with 1 Volume of Lime + 1Volume of Sand + n% of Charcoal

3.3. Interpretations

- The addition of charcoal in mortars of air lime accelerates the phenomenon of hardening for certain percentages of addition 10 %; 20 % and 30 %. For the others percentages, 40% and 60% the opposite occurs and the hardening takes more time see Figure 4.
- The charcoal known to absorb moisture must be added in an optimum quantity because the excess inhibits the

corrosion, on the other hand, its presence is beneficial it is a porous material that traps carbon dioxide and releases it gradually. This accelerates the carbonation and hardening of the mortar according to the following reaction

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

- The decrease in the proportion of sand in the mortar is favorable because it improves Setting time Figure 5.
- The formula with a volume of sand gives a faster hold than the one with a ratio of binder / granulate = 1/2. This dosage approximates those currently used in cement-based casing work (1000 kg of cement / m3 of dry sand) Figure 6, Figure 7.
- Mortars 1L+1S had better results than the others and would be the choice for the second stage.

3.4. Second stage: Introduction of Crushed Bricks

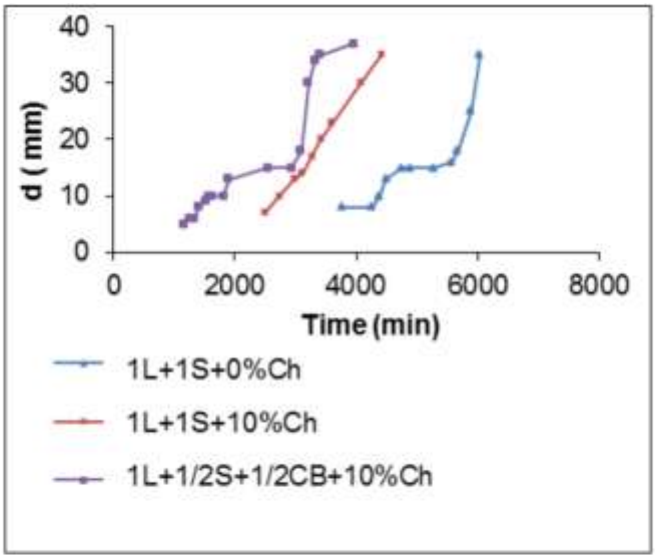

Figure 8: The variation of "d" with the time of mortars with and without charcoal and crushed bricks (**10%**)

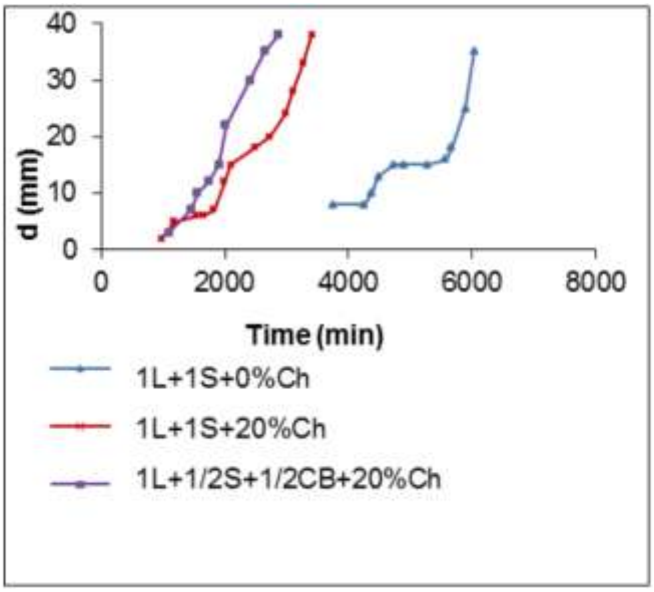

Figure 9: The variation of "d" with the time of mortars with and without charcoal and crushed bricks (**20%**)

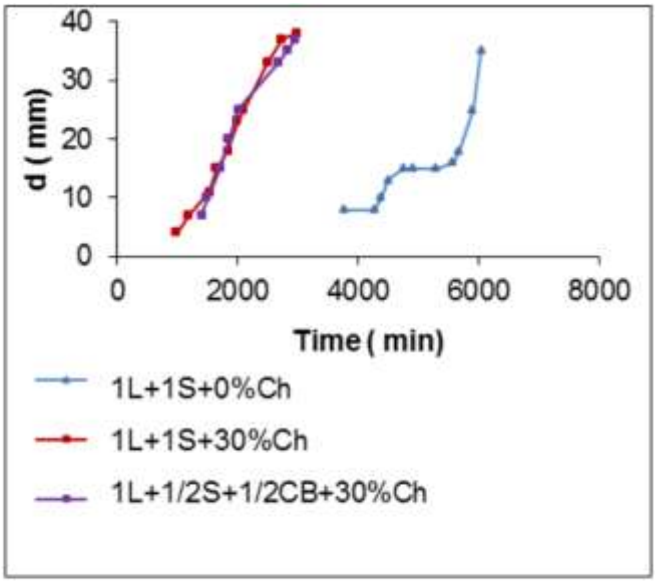

Figure 10: The variation of "d" with the time of mortars with and without charcoal and crushed bricks **(30%)**

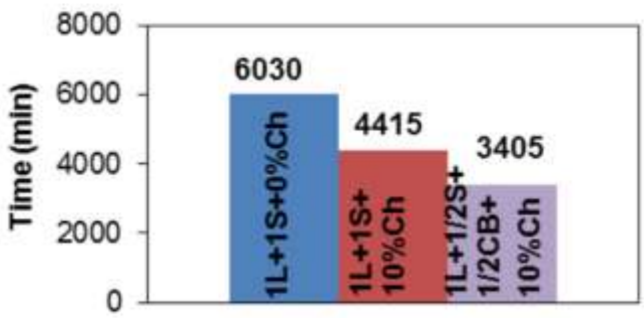

Figure 11: Final setting time of mortars with 10% of charcoal

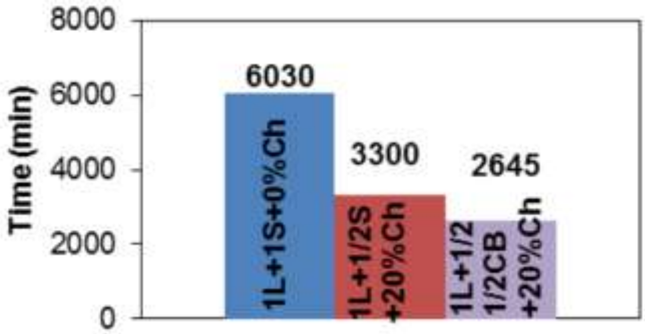

Figure 12: Final setting time of mortars with 20% of charcoal

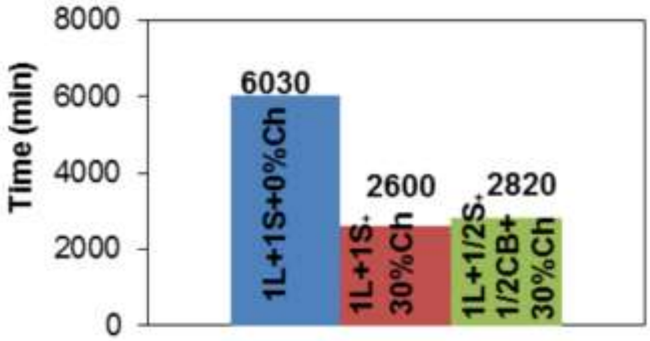

Figure 13: Final setting time of mortars with 30% of charcoal

Table 1: Percentage of gain of setting time

Percentage of charcoal addition (%)		10	20	30
Percentage of gain of setting time (%)	1L + 1S + 0% Ch	26,78	45,27	56,88
	1L + 1/2S+ 1/2CB	43,53	56,13	53,23

3.5. Interpretations

- The addition of crushed bricks reduced the start setting time and the final setting time of lime mortars with 10% and 20% of Charcoal Figure 8, Figure 9, Figure 11 and Figure 12
- The addition of crushed bricks to the mortar with 30% of charcoal, has an inverse effect and the setting time increases Figure 10 and Figure 13
- 1L + 1S + 30% Ch mortar, and 1L + 1/2S + 1/2CB + 20% Ch mortar, have almost the same final setting time Figure 12, Figure 13 and Table1

4. Mechanical tests

4.1. Manufacture of mortar specimens

Prismatic specimens of square cross-section "4 × 4 × 16" were produced, Figure 14, with:

- A standardized mixer.
- Standardized molds for making 3 prismatic specimens.
- An impact device allowing 60 shocks to be applied to the molds by dropping them from a height of 15 mm ± 0.3 mm to the frequency of a fall per second.

Figure 14: Specimens 4x4x16

4.2. Results

After being cured for 28 days, compressive strength was measured, Figure15, and table 2 presents results of compressive strength

Figure 15: Compression test

Table 2: Compression strength of mortars

	1V Lime + 1/2VSand+ 1/2V Crushed Bricks		
Percentage of charcoal addition (%)	10	20	30
Mortar Compression Resistance (MPa)	1.027	1.262	0.984

4.3. Interpretations of mechanical test

As shown in table 2 the compressive strength of aerial lime mortars is relatively low with and without additions.

However, it should be noted that these resistance values are obtained after a maturation of only 28 days and that many authors have observed an improvement in the mechanical strength of lime-based mortars with the maturation time, The mechanical strength of the lime-based mortar improves with ripening time and it can thus be assumed that the mortars made may have more interesting resistances over time due to the carbonation of the lime which exceeds 70% to 90 days of age [2].

The dispersion of values poses some problems in interpreting these results. The fact of obtaining a compressive strength which decreases with an addition of 10% of charcoal, increases with 20% of the same addition and decreases again with 30%, can be explained by the existence of an optimal proportion. The excess of charcoal will lead to more water in the mortar, which inhibits the carbonation and even reverses it.

5. Water absorption: Karsten permability

5.1. Test device: figure16

- Glass absorption tubes, graduated
- Modeling clay
- Graduated water bottle

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Figure 16: KARSTEN permeability test device

5.2. Principle

The test is carried out using prismatic test specimens "15 × 15 × 15 test pieces" figure 17.

Figure 17: Specimen 15x15x15

The measurements after the water filling of the pipe consist of readings of the decrease in the level of water in the tube as the water is absorbed by the material figure18.

5.3. Results

The obtained results can be plotted on a graph (where the volume of water absorbed kg / m2 or ml / cm2 is plotted as a function of hour or minute) figure 18.

Figure 18: Measurement of water absorption

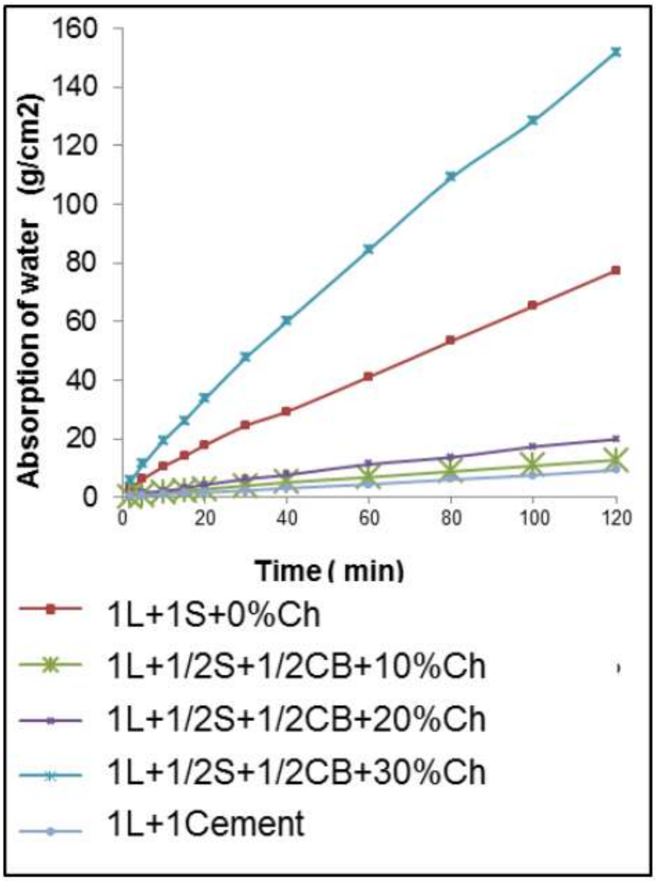

Figure 19: Absorption of water as a function of time

5.4. Interpretations

- Absorption decreases markedly with the addition of 10% and 20% charcoal, however, the addition of 10% gives lower absorption values Figure 19.
- It can also be seen that the absorption increases markedly for mortar with 30% of charcoal Figure 19.
- By comparing the water absorption of lime mortars with charcoal and crushed bricks with that of cement mortars, it is noted that the mortar of formula 1L + 1 / 2S + 1 / 2CB + 10% Ch possesses a water absorption Very close to that of mortar based on cement Figure 19.

5.5. Determination of permeability coefficient

The purpose of the test is to determine the water permeability coefficient of mortar of aerial lime. The permeability coefficient was calculated using Equation (1)

$$K = \frac{L}{t} + \frac{s}{S} + Ln\frac{h_1}{h_2} \quad (1)$$

Where:

- **h_1**: initial level of water in the tube (or initial hydraulic load)
- **h_2:** final level of water in the tube (or final hydraulic load)
- **t:** time to change from h_1 to h_2
- **s**: section of the piezometric tube (0.55cm^2)
- **S**: section of the sample (4.9cm^2)
- **L**: height between the permeametric inlet and outlet ports(13.25cm)

- **K**: Permeability coefficient (m / s)

5.6. Interpretation of permeability test

Table 3: The coefficient of permeability

	t (s)	h_1 (cm)	h_2 (cm)	K (m/s) (10^{-5})
1VL +1V S	180	3.9	2	7.11956
1V L +1/2S + 1/2CB + 10 % Ch.	600	2.4	1.2	2.21684
1V L +1/2S + 1/2CB + 20 % Ch.	600	3	1.4	2.43749
1V L +1/2S + 1/2CB + 30 % Ch.	120	3.5	0.5	76.3254
1V Cement + 1V S	600	1.5	1.1	0.991945

- The coefficient of permeability decreases markedly with the addition of certain percentages of charcoal Table 3.
- The addition of 10% charcoal reduces the permeability by 68, 86%.
- The addition of 20% of charcoal reduces the permeability by 65, 76%.
- This same addition, and with a percentage of 30%, on the contrary increases enormously this coefficient of permeability 337, 06%
- These results lead to the conclusion that there is a certain percentage which represents an optimum from which the effect reverses and the permeability, after being improved, begins to increase. Mortars based on lime and carbons behave like a sponge which traps the water within it and restores it by evaporation. They are mortars with a high hygroscopic power and, moreover, permeable to steam, which avoids condensations in the mass and on the surface.
- This reduction is due to the pozzolanic effect on the acceleration of the setting. Finely ground pozzolana reacts in the presence of moisture with the alkaline or alkaline earth hydroxides of natural lime to form compounds with hydraulic properties.

6. General Interpretations

The charcoal and crushed bricks additions favor the pozzolanic reaction and the carbonation and influence the different mechanical properties and transfer of the mortar. Indeed, the pozzolanic compounds present in the crushed bricks and even in the charcoal can react with the lime, which gives, in particular, a finer porosity distribution, a denser microstructure, and lower transfer properties than those of the base formulation, especially in the long term. Waterproofing and mechanical resistances, measured at 28 days, are likely to increase considerably with carbonation, which takes place largely between 28 days and 90 days (more than 50%) [2]. the transformation of portlandite into calcium carbonate is accompanied by an increase in volume, thus clogging the pores and impeding percolation by water

7. General Conclusion

This study concludes that the addition of 20% of charcoal to a basic formula of 1V lime + 1 / 2Vsand + 1 / 2V crushed bricks results in an improved catch, permeability, and resistance to compression Table 4.

The permeability at 28j of this mortar approaches that of cement and the effect of carbonation will only reduce this difference. These Results are more interesting because the energy and environmental issues are great. However, studying the durability of these mortars, with alternating cycles imbibition-drought, is important to pronounce more.

Table 4: The characteristics of the various formulations

Mortars	Lime	Lime + crushed bricks +% of Charcoal			Cement
		10%	20%	30%	
Final setting time (min)	6030	4415	2645	2820	--------
Compression strength (MPa)	1.165	1.027	1.262	0.984	--------
coefficient of permeability K (10^{-5} m/s)	7.119	2.216	2.437	76.32	0.991

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Author Profile

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