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Alkali activated compressed earth blocks – the one-part mixture method

Earth, one of the first materials used by man for civil construction, has gained prominence once again due to renewed interest in sustainable construction. Compacted earth block (CEB) construction is widespread and typically employs cement for stabilisation, however a new method of stabilizing blocks has been researched that uses geopolymers. There is as yet no clearly defined way of making geopolymeric blocks, and there are several difficulties involved, such as the fast setting time and blistering on the mixture. This research aims to test an experimental methodology to make alkaline activated earth compacted blocks, based on geopolymer one-part mixtures, where only a dry mixture prepared by mixing a solid alkali-activator with a solid aluminosilicate precursor is needed in addition to water.

For this research, different combinations of materials – sodium hydroxide, hydrated lime and sodium silicate as activators and metakaolin as precursor – were used to make the CEBs using the methodology described. The earth was mixed with the activators and precursors and water then added. The resulting blocks were tested for compression strength and water absorption by immersion and capillarity tests.

The results achieved were satisfactory. The chemical composition of the materials was determined using an FRX test, and the blocks exhibited a compressive strength of around 3 MPa. As the method used is considered easy and safe, there is potential for some improvement to achieve better results.

Introduction

Numerous buildings of diverse kinds testify to the strength and durability of earth over the ages (TORGAL, JALALI, 2012). While various different earth building techniques have arisen, to meet the challenges of current construction requirements, stabilisation methods have been employed to improve the material's workability, strength and durability.

Compacted Earth Blocks (CEB) employ the means of compression to provide a degree of inherent material stabilisation, but cement is also frequently added to improve mechanical compression (CHAMPIRÉ et al., 2016).

Geopolymers represent an alternative to cement that can also be used in the construction field. Davidovits (1976) was the first to introduce the term geopolymer, also called polysialates, which are materials with a large molecular chain consisting of silicon, aluminium and oxygen and have an amorphous to semi-crystalline structure.

This research aims to test an experimental methodology for stabilising CEBs using geopolymers based on one-part mixtures, in which the solid alkali activator and a solid aluminosilicate precursor are mixed in dry form and then water is added (LUUKKONEN et al., 2018).

Methodology

The earth (with clayey characteristics) was sieved (mesh 4 mm) and packaged in plastic barrels. The metakaolin used as the precursor was produced by BBM Minérios Industry. The characteristics of both materials were determined using X-ray fluorescence spectrometry analysis. The amount of metakaolin was fixed at 8% as a function of the earth mass.

The activators used were sodium hydroxide (NaOH) and hydrated lime, and they were mixed in the solid state. Sodium silicate was also used in some mixtures to correct the silica content.

Mix	Molar Ratio NaOH	Molar Ratio $Ca(OH)_2$	Si/Al
1	15	15	4.5
2	0	15	4.5
3	15	0	4.5
4	0	0	4.5
5	15	15	3.95
6	0	15	3.95
7	15	0	3.95
8	0	0	3.95
9	7.5	7.5	4.22
10	7.5	7.5	4.22
11	7.5	7.5	4.22

Table 1 Description of the mixtures

01 The mixing result

The number of samples, mixes and tests were defined by experimental statistical planning, with three input variables (2^3). With these planning definitions, nine distinct mixtures and three central points were made. The chosen variables are shown in Table 1.

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The sodium hydroxide molar ratio was determined by values close to the levels adopted by Pinto (2004) and Vassalo (2013). The molar ratio values of the hydrated lime were determined based on the NaOH ratio. The silica/alumina ratio was determined from the proportion of these elements found in metakaolin and based on parameters suggested by Davidovits (1982).

All blocks were cured at 70°C over 5 hours, as per parameters defined by Jaarsveld et al. (2002) and Teixeira (2017).

For each mix, 9 blocks were made and after 7 days were submitted to compression strength and to water absorption tests, using 3 samples for each test.

The mixtures were blended in a concrete mixer and then the blocks compressed using a hydraulic press from Eco Brava that can produce one block at a time.

After compaction, the blocks were left to rest for 24 hours covered by a plastic tarp to retard too rapid water loss and the occurrence of efflorescence and then placed in the kiln.

For the water absorption by capillarity test, the methodology described in the Compressed Earth Blocks Testing Procedures manual was used. Immersion and compression tests were performed according to NBR 10836. The load was applied at a speed of 10 mm/s.

Results

XRF

Table 2 presents the XRF results.

Methodological results

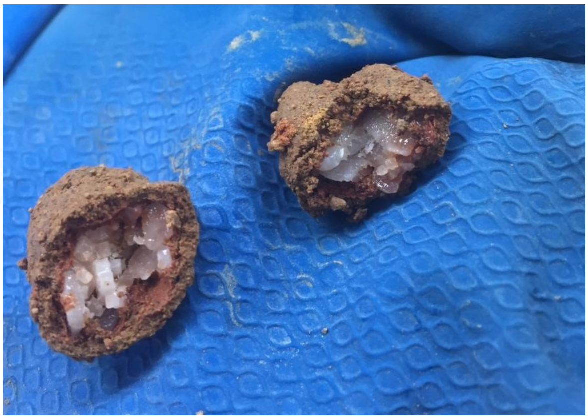
The method used in this research proved to be quite productive. Furthermore, a very dispersed and ho-

Table 2 Chemical composition of the earth

Oxides	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	ZrO_2	Outros
%	49.22	16.18	25.28	6.83	1.20	0.56	0.73

Table 3 Chemical composition of the metakaolin

Oxides	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_20	MgO	Outros
%	56.71	24.21	12.84	3.05	2.59	0.04	0.56



02 Unreacted sodium hydroxide encased by the earth

03 Sample made with powdered sodium hydroxide

mogeneous mixture was obtained with just a few pellets as can be seen in Figure 1.

Observations showed, however, that the NaOH particles were surrounded by the earth because their large crystalline structure meant they did not react completely (Figure 2).

One approach to solving this problem was to pulverize the hydroxide. This alternative, despite presenting a more positive result (Figure 3), proved to be dangerous due to the reactivity of the hydroxide. Consequently, research continued using scaled hydroxide.

Compression tests

The mechanical compression strength test results are shown in Table 4. Mix 1 is the only one to provide a compression strength higher than 2 MPa that is deemed suitable for use in sealing masonry according to the soil-cement block standard NBR 8491 (ABNT, 2012).

Also apparent is that the presence of hydrated lime in the mixture provides a strength gain over and above the positive influence of adding silicate.

The fact that the activators and precursors were added in a solid state to the earth may have hindered the effective occurrence of alkaline activation, which would explain the below-expectation results.

Immersion tests

The results of water absorption by immersion were mostly satisfactory. The test was undertaken according to the NBR 8491 (ABNT, 2012). Mix 8 did not have any activator, and mix 4 had only silicate, which is a possible reason for their weak result when exposed to water.

Table 4 Compression strength test results

Mixes	1	2	3	Average results
1	2.85	3.58	3.50	3.31
2	0.51	0.75	0.61	0.62
3	2.09	1.40	1.47	1.65
4	0.53	0.46	0.56	0.52
5	1.32	1.58	1.39	1.43
6	0.37	0.24	0.31	0.31
7	1.20	1.20	1.20	1.20
8	1.05	0.80	0.72	0.85
9	1.08	1.12	1.17	1.12
10	1.67	2.21	1.63	1.84
11	2.33	2.12	0.96	1.80

Table 5 Immersion test results

Mixes	1	2	3	Average results
1	5.62	6.31	7.02	6.31
2	13.62	14.38	16.22	14.74
3	9.89	8.62	7.59	8.70
4	–	12.20	–	12.20
5	10.80	11.94	11.58	11.44
6	26.59	24.15	23.65	24.80
7	12.78	9.57	8.64	10.33
8	–	–	–	The block broke
9	6.54	7.34	45.68	19.85
10	10.12	8.64	10.77	9.84
11	10.38	9.87	12.13	10.79

Mixes	1	2	3	Average results
1	16.98	13.80	15.40	15.39
2	4.77	4.78	3.37	4.31
3	11.46	11.82	11.67	11.65
4	11.68	13.98	12.97	12.88
5	5.38	7.54	7.65	6.86
6	28.52	31.63	23.06	27.74
7	3.32	8.86	8.36	6.85
8	6.33	6.47	6.93	6.58
9	4.10	5.98	4.52	4.87
10	2.62	3.43	4.64	3.56
11	6.81	7.50	5.13	6.48

Table 6 Capillarity absorption results

04 Mass loss

Here again, mix 1 stands out: in addition to exhibiting the best compression strength it also had the lowest water absorption, highlighting its potential for possible application in civil construction.

Table 5 shows the results of the immersion tests.

Results of capillarity absorption tests

The results of the capillarity absorption tests were not conclusive (see Table 6).

The results of capillarity absorption appear to have been compromised by the mass loss of the samples. The results of some mixes – such as mixes 2, 7 and 8 – are masked by their mass loss. The results appear to be good but when compared with the results of immersion and compression, are inefficient. A further point of interest is the results for mix 1: its capillary absorption result was unsatisfactory but this was one of the few mixes that had not had mass loss by immersion and exhibited good absorption results by immersion as well as good compression results.

Conclusion

The results show that further studies and research is needed on the mixing method so that alongside improving productivity and workability, the strength of the blocks can be increased to a level that enables them to be used not just as sealing masonry but also in a loadbearing function. If it is possible to produce such blocks at a large scale, this activation technique has the potential to progress beyond the scientific community and be adopted in the building sector.

The tests shows that hydrated lime and sodium silicate alone were not sufficiently effective, but when combined with NaOH they significantly contribute to the mix strength. Their use in geopolymeric CEB is therefore beneficial and can be adopted to improve strength. Furthermore, the combination of materials must be used with good compaction for good results.

Finally, it can be seen that the alkaline activation of Compacted Earth Blocks is a research field that still needs further research but is also very promising due to the sustainable character and technical potential of the method. Continued research is vital to find viable and productive solutions that are suitable for adoption on a wider scale.

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