Calcined Clays and Geopolymers for stabilization of loam structures for plaster and bricks

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Abstract. Loam is a very ecological building material with a great potential. It is found worldwide and completely recyclable. Under dry conditions, loam develops high strength values. However, loam is not moisture-resistant. Permanently acting moisture reduces the strength dramatically. The idea to improve the water resistance of loams is adding materials to the loam with the same basic structure. Therefore, Metakaolin, Calcined Clay, here so called Metaclay and a specially developed Geopolymer were selected. Blends of 4 different loams with different amounts of these additives were produced and tested. Criteria for an evaluation are the dynamical modulus of elasticity and the water resistance. These studies were supplemented by structural investigations using a light and a scanning electron microscope and XRD. The results are very interesting and the effects depends strongly on the kind of loam too. Not all additives lead to an improving of the mechanical properties. Nevertheless, not the samples with the highest mechanical values show the best water resistance behavior. Obviously, a balanced structure between loam and additive particles is necessarily. Such structures are not so dense but enough resistant to water to guarantee the positive property of fast water absorption and delivery of natural loams. The service lives of the loam prisms could be increased from certain minutes to several days. Best results are obtained with geopolymer based materials as an additive. This is not so surprising because both the loam and the geopolymer form alumino silicate structures during hardening.

Keywords: loam bricks, Geopolymer, Calcined Clays, water resistance, service live.

1 Introduction

Loam is an ancient building material and was used over the millennia all over the world. The reasons therefore are very simple, because loam has many positive properties. Loam can be found in all regions of the world, requires little energy for production and processing and is completely recyclable. Under dry conditions, loam develops high compressive strength, the tensile strength can be improved by addition of fibers. Fat loam can be emaciated by addition of sand or other aggregates. The production of insulation materials is possible too by addition of light-weight aggregates to the mixtures. It is logical that not so much literature exist. Some patents [1,2] deals with the improving of loam properties by addition of cementitious materials. The focus here was to increase the strength, of course the water resistance and other durability values. Already in 1950 [3] mixtures between loam and concrete to attach airfields and temporary roads were investigated. However, this is not the favorite solution for the loam worker today.

It is to take into account that loam has an important negative behavior, namely it is not moisture-resistant. Permanently acting moisture reduces the strength dramatically. Most of all discussed solutions and materials added to the loam to solve this problem lead to a compression of the natural loam structure. Needless to say is that the addition of cement to loam and vice versa give problems in the workability of mortars and concretes. Additionally a further point of view is that ecologically orientated people will not accept a combination between loam and cement. Another research direction was described in [4] namely the stabilization of clay structures by addition of natural polymers and wood fibres.

That`s why the idea was born to combine materials with approx. the same basic structure elements. Loam is a natural mortar and consists of clay minerals as the binding part and quartz grains with different sizes as a structural scaffold. Clays have aluminum and/or alumino silicate structures, which can form sheets and networks. The hardening process bases on physical interactions to form Van-der-Waals bonds. If moisture escapes, the particles can be very close to each other. On the other hand, if moisture is taken again, the structures can swell and the distance between the particles is increased. The influence of water and moisture is not a chemical dissolution but a physical destruction process.

The search for materials, which are available and from a structural point of view suitable too, results in testing of geopolymers and other similar substances. There are not so much information on this combination in the literature. In [5] a combination of hydrothermal burnt clay with a lightweight aggregate was discussed to form clay bricks with an improved insulation behavior. The aim “strong and heat insulating” could be reached. In [6] a combination of loam with other additives is mentioned. For these investigations, an activated loam, called as an alumino silicate compound, was mixed with different mineral additives to improve mechanical and durability properties. The activated loam binder is made up of clay and a reactive alumino silicate compound, namely a geopolymer produced with metakaolin and a highly alkaline solution. In comparison to a conventional loam, the activated loam binder has achieved a higher strength and water resistance while maintaining the water vapor permeability. Exactly this is the aim of this research project however without any using of highly alkaline activator substances (sodium hydroxide).

2 Materials used

The investigations were performed with four different loams. Loam 1 (L1) is a swamp loam with a medium to strong binding behavior. Loam 2 (L2) is a glacial loam with a high amount of sand and silt, loam 3 (L3) is a loess loam with a relatively high lime content and loam 4 (L4) represents a sandy loam with a high amount of quartz and feldspars. Because of the different formations, the loams have also different compositions (chemical and mineralogical composition, grain sizes and grain size distributions).

The following **Tables 1A** and **1B** give an overview on the chemical and mineralogical compositions of loams selected for the investigations. **Fig. 1** shows the distribution curves of grain sizes of the loam materials, differences between the loams can be clearly seen. Dry material was measured what means that agglomerates may have formed.

Table 1A. Chemical composition of loams chosen.

Charge	L1 [w.-%]	L2 [w.-%]	L3 [w.-%]	L4 [w.-%]
SiO_2	64.39	84.17	77.01	81.55
Al_2O_3	16.16	7.76	10.89	10.16
CaO	0.98	0.31	0.60	0.17
Fe_2O_3	6.90	2.77	3.95	1.21
MgO	1.28	0.43	0.78	0.37
Na_2O	0.66	0.44	0.86	0.11
K_2O	2.06	1.66	2.47	1.73
TiO_2	0.91	0.47	0.81	0.81
loss on ignition	6.66	2.01	2.62	2.62

Table 1B. Mineralogical composition of loams chosen

Charge	L1 [w.-%]	L2 [w.-%]	L3 [w.-%]	L4 [w.-%]
quartz	37.5	69.1	54.5	64.8
clay	32.5	13.3	17.2	20.5
feldspar	17.8	13.5	21.9	11.1
oxide	8.8	3.9	6.2	2.5
carbonate	2.7	0	0	0

An important criteria of the loams used here is the grain size distribution, it gives information on the contents of sand, silt and clay particles.

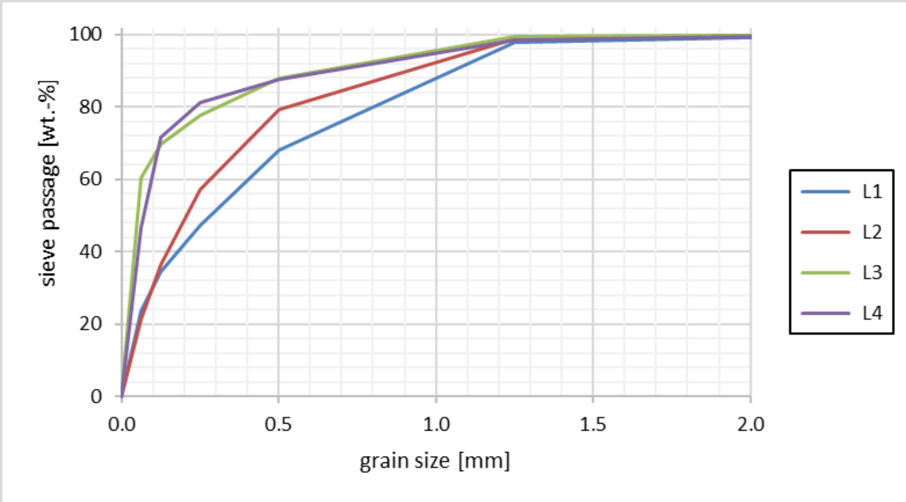

Fig. 1: Grain size distribution of loams investigated

Data of the Geopolymer, Metakaolin and Metaclay used as special additives are summarized in **Table 2**.

All additives are very fine grained and therefore they should contribute to the density increase of the loam samples.

Table 2. BET-surfaces of additional components

additive	A [m^2/g]	density [g/cm^3]
Metakaolin (MK)	18.94	2.605
Calcined Clay (MT)	14.73	2.615
Geopolymer (GP)	30.40	2.17

3 Performance

Samples for the investigations contain certain amounts of loam and additives. Of course, pure loam samples were also produced. The ratio loam/additive was varied between 10/1, 5/1 and 3/1. The last relationship is based on a typical mortar composition, however in difference to this all components are binder materials and the aggregate is the quartz content of the loam. The selected Si/Al ratio of the Geopolymer is 2/1 and based on preliminary investigations to create a geopolymer mortar for special uses [7]. The Geopolymer consists of two components, a siliceous residue with a high reactivity and an aluminate substance from the detergent production. The Si component accumulates as a slurry with a defined water content. In contact with the water from the slurry the aluminate component reacts to a alkaline solution, in which the Si part can be dissolved. The result is the formation of an alumino silicate network, a little bit similar to the loam structures. This formation process can be determined by using NMR investigations. **Fig. 2** shows the structure development of the Geopolymer compound.

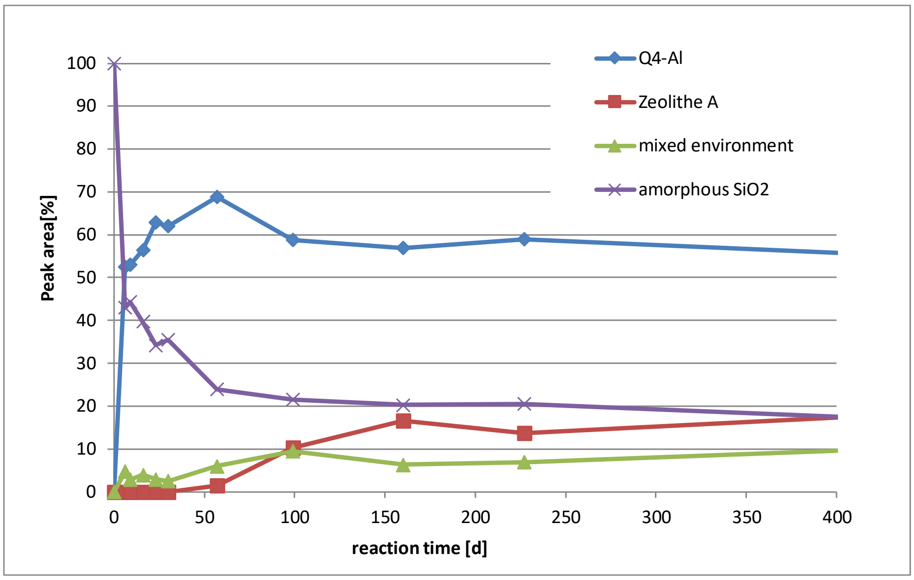

Fig. 2: NMR investigation results to demonstrate the different structures formed at different times in the geopolymer compound

The Metakaolin used is a common material called PowerPozz. It consists of approx. 55 wt. % SiO_2 and 41 wt. % Al_2O_3. The Metaclay material is a mixture of two clays with different compositions. It was burnt at 650-680°C in a rotary kiln. Characteristical values are summarized in [8].

The production procedure consists of several parts. In a first step, the loam and the aluminate component are mixed, grinded and homogenized dry. Because of the fact that the siliceous component is a suspension with a certain water content, the dry compound was added to the slurry and both were intensively mixed. Based on a brick technology for roof tiles, the material was pressed to 5-10 mm thick plates with a defined shape. The pressure was 80kN, converted to the test specimen surface 20 N/mm^2. The so produce samples can be seen in **Fig. 3**.

Fig. 3: Loam samples produced in the laboratory

This is what all test specimens look like. They are the basis for the further investigations.

4 Results

4.1 Dynamical Modulus of Elasticity

Fig. 4 shows the results of the development of the dynamical Modulus of Elasticity. The values were determined by using a non destructive method called Grindosonic. There are differences between the loam samples because of their different composition. It can be observed that an addition of Geopolymer in a ratio 10/1 leads not in all cases to an increase of the modulus. L2 indicates a raise, L4 even a decrease. Loam L3 produced with a ratio of 3/1, what means a higher amount of Geopolymer in the mixture, gives a strong increase of the modulus. Loam-Metakaolin and Loam-Metaclay mixtures have a lower strength in general in comparison to the starting materials. The results are very complicated and cannot clearly discussed in this way, that an addition of geopolymer or other additives leads under all condition to an improvement of mechanical properties. However, this was not also the aim of the investigations.

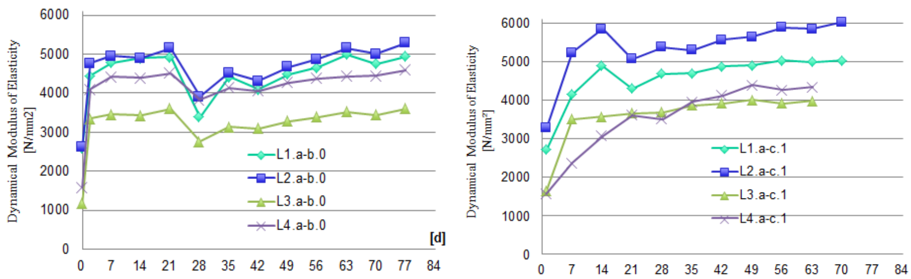

Fig. 4: Development of the Modulus of Elasticity of loam samples (left original, right 10/1)

4.2 Water resistance

The German standard DIN 18945 from 2018 contains requirements for the water resistance depending on the use of loam bricks. There are different test methods to determine the water resistance. One of them is the so-called immersion test. Geometrical defined samples are stored in a water bath so, that the water has always contact to the sample. The samples soak up the water until destruction. Bricks, which should be used outside, have to withstand this procedure for at least 10 minutes.

Soak investigations were performed with many samples and with different compositions. The time until destruction was measured automatically. The experimental setup is shown in the **Fig. 5**. Some samples especially the original ones were destroyed after a very short period of time, in general mixtures with additives stand longer. Very good results were obtained with an addition of Geopolymer in a ratio 10/1 loam:GP (in **Fig. 6** marked with **I**). The ratio 5/1 (in Fig. 6 marked with **II**) gives good results for the standing time of loam L2, but the suction height here is too large. The ratio 3/1 loam:GP (**III)** provides the worst results, what is a little bit surprising. Metakaolin and Metaclay are not so suitable because of the fact that such materials cannot lead a contribution for the structure formation process under neutral loam conditions.

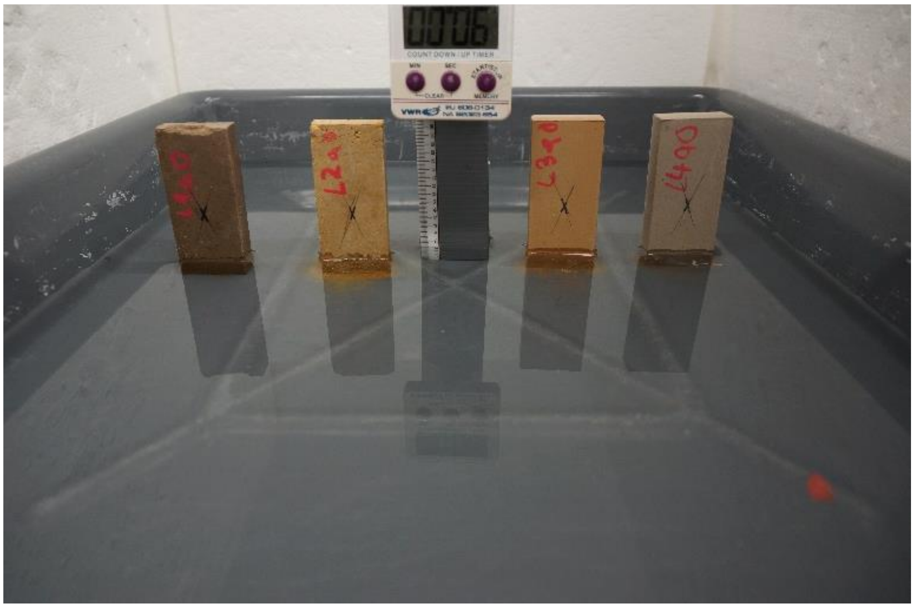

Fig. 5: Investigation setup for the determination of the water resistance

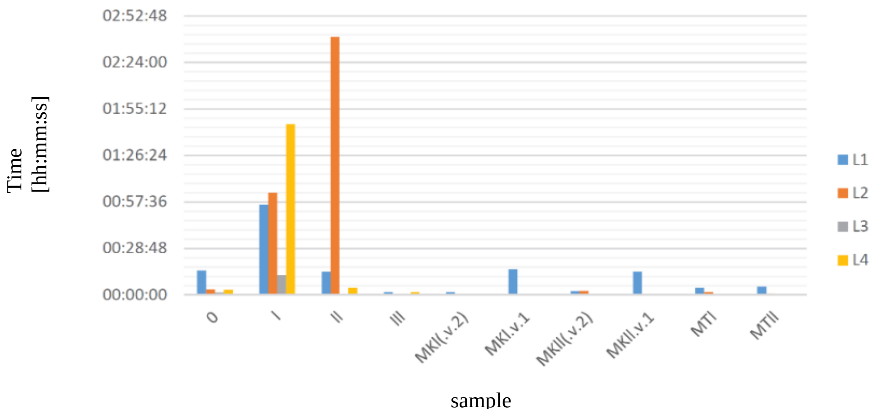

Fig. 6: Resistance against water uptake (the time of standing is shown)

Fig. 6 summarizes the results. In this figure the time of standing of the different mixtures is shown. MK stands for Metakaolin, MT for Metaclay. I, II and III represents the ratio between the loam and the additives respectively (I =10/1; II =5/1; III =3/1).

4.3 Structural investigations

The question here is: It is possible to find reasons for the observed water resistance behavior? XRD and SEM investigations were made to determine the mineralogical compositions with and without addition of Geopolymer. SEM investigations were performed to describe the structure of loam samples formed.

Differences between the loam compositions were already mentioned in Table 1A and 1B in section 2. Changes of loam or clay structures shall only be demonstrated with L2 as an example. The next **Fig. 7** contains XRD pattern of L2 with Geopolymer (10/1) at the beginning, after 14 and 28 days of reaction. The pattern demonstrates the decrease of 2-, 3- and mixed layer clay minerals. However, it can clearly be seen that a broad peak is formed during the reaction between loam and GP. The interpretation is not so clear, it could be a zeolite or an intercalated layer silicate (illite, vermiculite). In both cases obviously this phase leads to a stabilization of the loam structure L2.

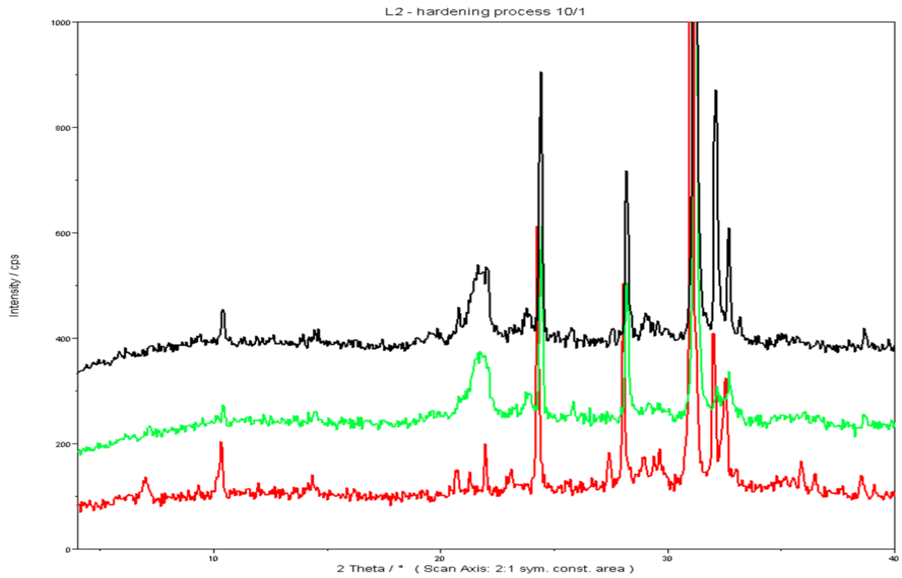

Fig. 7: XRD-Investigation results of L2 during reaction with geopolymer (L2/GP = 10/1)

SEM investigations support this result. **Fig. 8** documents the structure of L2 with GP under 1100x Mag (left) and under 3000x Mag (right). In the right picture swelling clay structures (in the middle) can be observed, what indicates that the XRD pattern can be interpreted in this direction.

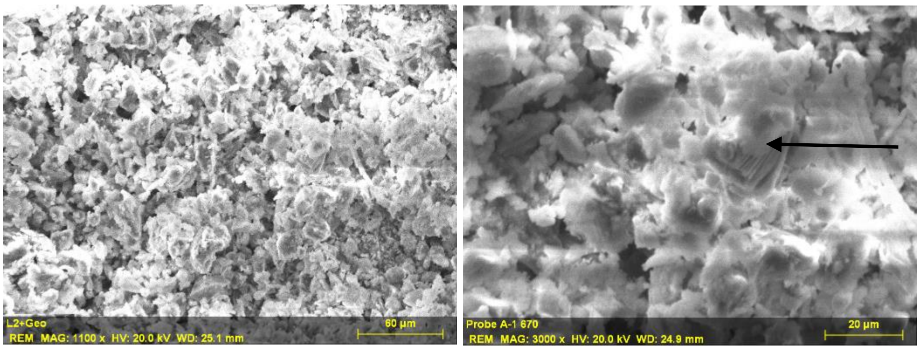

Fig. 8: SEM micrographs of loam-GP samples (here L2/GP = 10/1)

5 Conclusions

1. Loam as an ancient building material and a special Geopolymer as a new one can be mixed to create stabilized loam structures.
2. The properties depend on the loam (composition and grain size) and of course on the Geopolymer (here Si/Al ratio).
3. Important is to guarantee that only water is added to the system because of the ecological basis of the loam material.
4. Best results for structure development, modulus of elasticity and water resistance are obtained with a glacial loam (L2) in combination with a Geopolymer (Si/Al=2/1) with a ratio of 10 parts loam to 1 part Geopolymer.

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