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# Characteristics of lime treated soil in function of time

## Caractéristiques du sol traité à la chaux en fonction du temps

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**ABSTRACT:** The lack of sand in Belgium results into a high amount of sand import for civil engineering applications. By adding lime, clay and loam soils will look and act like sand. The treated soil can be used as a sand replacement for construction sand. This research starts with an extended literature review and parameter study to determine the soil characteristics. Subsequently, the characteristics of lime treated soil are analyzed in function of time. The methylene blue value, Atterberg limits, pH value and compressive strength are analyzed through proctor samples in function of time and compared with the untreated soil. Proctor samples are tested each week over a period of 24 weeks. Provisionally conclusions are a logarithmic increase of the compressive strength, while the plasticity index, methylene blue value and pH value decrease logarithmic in function of time. In the second part of the research, accelerated aging tests are performed on treated soil samples. Results of the Atterberg limits, pH value and compressive strength are compared to the literature review and test results with normal aging time.

**RÉSUMÉ:** Le manque de sable en Belgique se traduit par une quantité importante de sable importé pour des applications de génie civil. En ajoutant de la chaux, les sols argileux et limoneux ressembleront à du sable. Le sol traité peut être utilisé pour remplacer le sable de construction. Cette recherche commence par une analyse documentaire approfondie et une étude de paramètres pour déterminer les caractéristiques du sol. Par la suite, les caractéristiques du sol traité à la chaux sont analysées en fonction du temps. La valeur du bleu de méthylène, les limites d'Atterberg, le pH et la résistance à la compression sont analysés à l'aide d'échantillons traités en fonction du temps et comparés au sol non traité. Les échantillons Proctor sont testés chaque semaine sur une période de 24 semaines. Les conclusions provisoires sont une augmentation logarithmique de la résistance à la compression, tandis que l'indice de plasticité, la valeur du bleu de méthylène et la valeur du pH diminuent logarithmiquement en fonction du temps. Dans la deuxième partie de la recherche, des tests de vieillissement accéléré sont effectués sur des échantillons de sol traités. Les résultats des limites d'Atterberg, du pH et de la résistance à la compression sont comparés à ceux de la revue de la littérature et des résultats des tests avec une durée de vieillissement normale.

**Keywords:** lime, treated soil, soil stabilisation, compressive strength, curing time

# 1 INTRODUCTION

In Flanders there are many clay and loam soils available, but there is a lack of sand. This means that Flanders is highly dependent on imports from neighbouring countries. Clay and loam soils have a relatively low bearing capacity. These soils will have to be treated with lime and/or cement to make them suitable for use in civil construction. In this investigation, the soil will be treated with quick lime which makes the clay minerals look more and act like sand as a result of chemical processes. Soil stabilisation is a method that already existed in Belgium in the 50's and 60's through the construction of highways. In the last decades, there is more attention for soil stabilisation due to the lack of sand in Belgium.

Usage of lime in soil stabilisation has certain advantages: the addition of lime makes that an unusable mud turns into a driveable soil for construction machinery. As a result, the soil is less sensitive to humidity. The treatment of soils allows to reduce the heavy transport and the supply of building materials to a large extent. This means an important profit for the building contractor. Less transport results into less noise, less nuisance and less wear of the surrounding roads. The technique of soil stabilisation by adding lime to a certain soil allows the construction industry to use the natural raw materials for high-quality applications. The treated soil will act as sand so in that way the natural sand can be used in other construction applications. The treated soil can be used in an economic and qualitative way in road constructions. (Fediex, 2016)

The purpose of the investigation is to analyse the characteristics of lime treated soil in function of time. That way it can be examined how the treated soil will react after an amount of time. Following main research question is discussed in this investigation:

How do the characteristics of lime treated soil develop in function of time?

First of all, there is a compilation of literature performed to find out what is already known about this topic. A parameter study is done on the soil that is used during this research in order to determine the characteristics of the soil itself. Afterwards, the soil can be classified using SB250 (Agentschap Wegen en Verkeer, 2012). Finally three proctor test samples will be made for each time period. A time period is the amount of weeks the proctor test samples have been stored in a room of 30 degrees and a humidity of 90%. For example the proctor test samples of time period 10 will be tested after a rest period of 10 weeks. The research consists of 24 time periods and each week the proctor test samples will be analysed. The proctor test samples will be tested in a period of 24 weeks and after these 24 weeks it can be determined how the characteristics develop.

# 2 LITERATURE REVIEW

## *2.1 Principal soil stabilisation*

Soil stabilisation makes it possible to improve the geotechnical properties of a soil. The untreated soil is difficult to use in practical applications, but after stabilisation, soil becomes more granular and more workable in the field. These are mainly loam and clay soils which are very water sensitive. The treated soil can be used on small and large construction sites. It gives a technical, economic and ecological solution for the problems of the soil. Soil stabilisation will be completed by adding lime and/or cement.

Some applications of soil stabilisation in road construction are foundation of roads and cycle paths, completion of sewer slots and sand replacement for construction sand.

The addition of lime has two immediate effects on the behaviour of the soil.

*(1) Flocculation:*

Addition of lime modifies the electrostatic fields between the clay particles. This results immediately in a change of fine clay particles into stable granules. As a result, the soil is more granular due to the formation of Ca(OH)2 or CaOH bridges between the clay particles. The granules are smaller, not sticking, look dryer and have a lighter colour. The addition of lime causes a reduction in the plasticity index and a reduction in the maximum compacted density. Lime increases the strength of almost all types of soil. The soil turns from a plastic state into a solid state. In this way the soil is more workable and easier to compact. The maximum dry density decreases and the optimal water content increases after stabilisation.

The formation of stable granules improves the geotechnical properties of the soil. The plastic limit increases, which means the plasticity index decreases. The Proctor curve will have a flatter shape after the addition of lime. The change in structure depends on the presence and nature of clay minerals. The plasticity index of the soil has to be higher than 5% to be able to treat soil with lime. (OCW, 2010)

(2) Vaporisation:

The addition of lime provides an immediate reaction. This reaction results in an exothermic reaction. As a result there is a reduction of the water content by evaporation and hydration. This will be discussed in the paragraph 2.3.

## 2.2 Lime

Lime has been used as a soil stabilizer for roads since a long time. Lime is produced from natural limestone. The type of lime is based upon the parent material and production process. There are five basic types of lime according to Purushothama Raj (Purushothame, 1999): high-calcium quicklime [CaO], dolomite quicklime [CaO + MgO], hydrated high-calcium lime [$Ca(OH)_2$] and normal hydrated dolomite lime [$Ca(OH)_2$ + MgO].

High-calcium quicklime has been used in this investigation. Quicklime is produced from limestone which is pulverized and burned up to temperatures of 900°C. The calcium carbonate breaks up in calcium oxide and carbon dioxide. This process takes place in a horizontal or vertical oven. (Libbrecht, 2010)

Quicklime has a particle size distribution of 0-2mm. The lime reacts slower when the lime has a larger particle size distribution. The quantity of available calcium oxide indicates the chemical purity. This quantity has to be higher than 85% for soil stabilisation applications.

## 2.3 Mineralogical change

The increase of strength is the result of the chemical reactions that takes place: dehydration, ion exchange, flocculation and pozzolanic reactions. These processes can be divided in two groups: modification and stabilisation. (Libbrecht, 2010)

(1) Modification:

Modification starts in the first 24 hours after adding lime to the soil. Modification includes dehydration, ion exchange and flocculation.

During the first phase a highly exothermic process between CaO and $H_2O$ takes place.

$$CaO + H_2O \rightarrow Ca(OH)_2 + heat$$

The production of heat leads to the evaporation of pore water.

Flocculation is the process where clay particles get together in stable granules. The structure of these volumes are weak, because the compound between the molecules are not that strong. This is in contrast compared to the crystallization which attach the molecules strongly to each other.

The particles of untreated fine-grained, clayish soils have a negatively charged surface. This surface attracts free cations, positively charged ions like $Na^+$, $Ca^{2+}$ and $Mg^{2+}$, and water dipoles. As a result, a water diffuse layer is formed around the particles. (Boehme et al. , 2016)

(2) Stabilisation:

Stabilisation includes the pozzolanic reactions and refers to the processes which are much slower. They cause a long term increase in strength by the crystallization of hydrated calcium silicates (CSH) and hydrated calcium aluminates (CAH).

The reactions between lime and water results in an alkaline environment. As long as there is enough water, aluminium oxide and silicon dioxide will dissolve. This leads to an ion exchange with $Ca(OH)_2$ resulting in CAH and CSH. (Libbrecht, 2010)

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$$
$$Ca^{2+} + OH^- + SiO_2 \rightarrow CSH$$
$$Ca^{2+} + OH^- + Al_2O_3 \rightarrow CAH$$

### 2.4 Effect on compressive strength

Research of Chong and Kassim at the university of Malaysia investigated the effect of lime on the compressive strength of Pontian marine clay (Chong and Kassim, 2014). They researched the effect of curing time on the compressive strength and consolidation characteristics of lime treated soil (Pontian marine clay). The main results are presented in Figure 1. The result indicated that the addition of lime successfully increased the strength, stiffness and workability of the soil. The unconfined compressive strength UCS of stabilized soil was increased by 49% at age of 56 days. The UCS of lime stabilized Pontian marine clay gradually increased in function of time and surpassed the strength of unstabilized soil at age 14 days. Afterwards, the strength increase rate was more rapid and reached 1,5 and 2,5 times the unconfined compressive strength unstabilized soil at age 56 days and 224 days respectively. Finally the strength increase continues. The pozzolanic reactions may continue in 1 to 5 years or more with the condition that there is adequate lime and availability of silicon and aluminium.

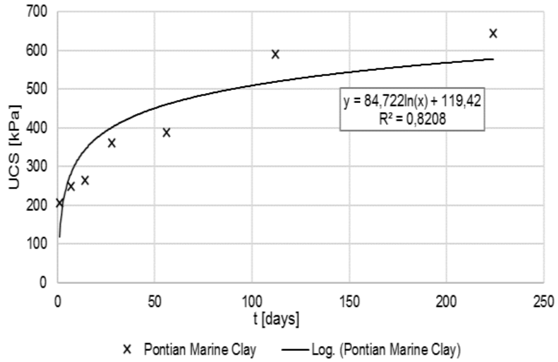



*Figure 1: UCS Pontian marine clay (Chong and Kassim, 2014)*

### 2.5 Effect on Atterberg limits

Professor H.N. Ramesh did an investigation in 2013 at the university of Bangalore in India (Ramesh et al. , 2013). The purpose of the investigation was to investigate the effect of lime on the Atterberg limits of a local soil. The soil was treated with 3% lime. The graphs are presented in Figure 2. The addition of lime leads to an increase in liquid limit from 57,9% to 61,3%, which is an increase of 6% of the beginning value (57,9%) due to the flocculation of clay particles. The plastic limit of BCS and MT immediately increases from 25,8% to 36,6% after the addition of lime. This is an increase of 42% of the beginning value (25,8%). After this increase, the values become more constant. The initial increase is due to the decrease in the diffused double layer thickness of clay particles and also flocculation of clay particles.

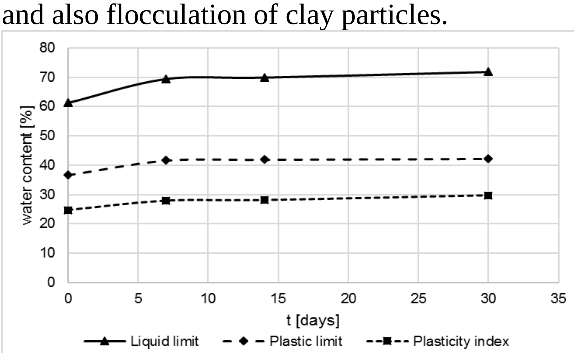


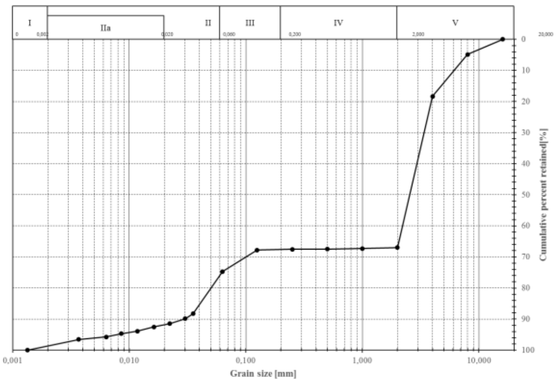

*Figure 2: Atterberg limits BCS+MT (Ramesh et al., 2013)*

# 3 PARAMETER STUDY

The first part of the laboratory research is a parameter study in order to determine the soil characteristics. Following tests are performed during the parameter study: the Atterberg limits test to determine the liquid limit, plastic limit and the plasticity index. The methylene blue test to calculate the methylene blue value MBV, the pH test to determine the optimal lime content $L_{opt}$, the specific gravity G, the particle size distribution, the proctor test to find out the maximum dry density $\rho_d$ and the optimal water content $w_{opt}$ as a result of the proctor curve. At last, the swelling test was done to determine the volumetric growth $G_v$. The results are shown in Table 1 and the sieving analysis.

*Table 1: Parameter study*

| Parameter | Standard | Result |
|---|---|---|
| Liquid limit | CEN ISO/TS 17892-12:2004 | 26,30 % |
| Plastic limit | CEN ISO/TS 17892-12:2004 | 13,20 % |
| Plasticity index | CEN ISO/TS 17892-12:2004 | 13,10 % |
| MBV | NBN EN 933-9 | 15,3 g/kg |
| $L_{opt}$ | ASTM D 6276 | 1 % |
| G | ASTM D 854-06 | 2,614 |
| $\rho_d$ | NBN EN 13286-2AC | 1857 kg/m³ |
| $w_{opt}$ | NBN EN 13286-2AC | 11,99 % |
| $G_v$ | NBN EN 13286-49 | 7,86 % |




The type of soil can be classified by using the standard in Belgium. According to the standard, the soil can be classified as a loamy sand, due to the plasticity index and the MBV, which can be treated by adding lime and/or cement.

Three proctor test samples are made for each time period. The proctor test samples consist of ±2 kg loamy sand, 1% (=$L_{opt}$) lime and 11,99% (=$w_{opt}$) water.

# 4 TEST RESULTS

There are three proctor test samples for each time period. After a rest period of x weeks, depending on the time period, the complete proctor test samples were tested on compressive strength (diameter = height ≈ 0.1 m). The broken soil will be used to do the methylene blue test, the Atterberg limits test and the pH test. The methylene blue test was completed twice and the pH test three times for each time period. The methylene blue test is a test to determine the amount and activity of clay in the soil.

The graph of the compressive strength in function of time is presented in Figure 3. The compressive strength is increased logarithmic in 24 weeks from 0,476 MPa to 0,865 MPa. This is an increase of ±82%. The graph has an increasing gradient in the first eight weeks, with an increase of ±70%. After eight weeks (time period 8), the graph has a more constant, flatter gradient.

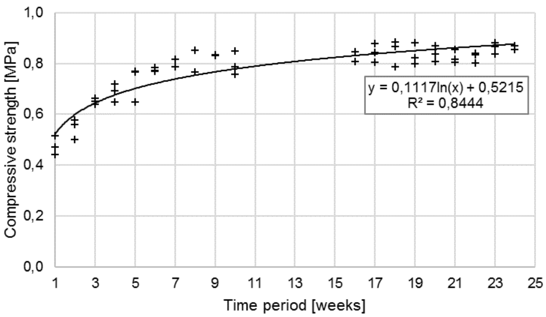



*Figure 3: Compressive strength in function of time*

Figure 4 demonstrates the methylene blue value in function of time. De methylene blue value is decreased from 15,3 g/kg to 8,6 g/kg in 24 weeks. This means a decrease of ±44%. The graph is decreasing logarithmic in the beginning, but after time period 18, the value remains constant. The MBV detects the amount of activity of clay in the soil. The MBV decreases with 44% which means the soil will look and act more like sand.

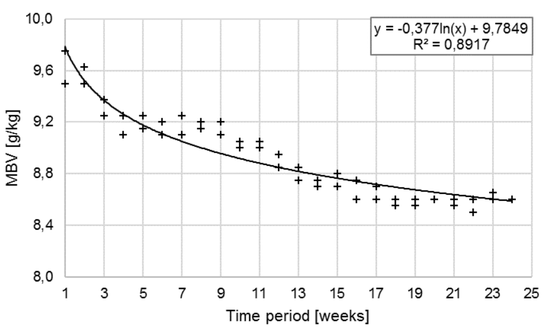



*Figure 4: MBV in function of time*

The liquid limit is the water content at which a soil changes from a plastic to a liquid state. The water content is corresponding to a cone penetration of 20mm in the fall-cone method. The graph is shown in Figure 5. The liquid limit increases in the first three time periods. The liquid limit increases until a maximum value of 28,61%. In comparison with the untreated soil, the liquid limit increases with 9%. After this growth, the liquid limit starts decreasing, where the value fluctuates around 26%.

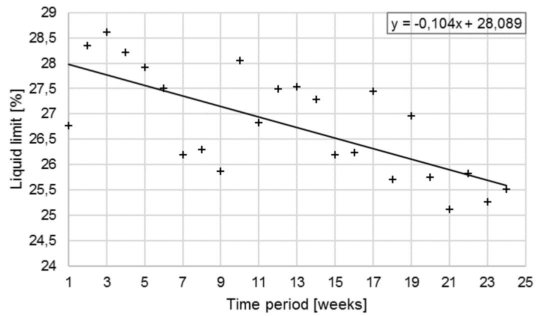



*Figure 5: Liquid limit in function of time*

The plastic limit of soil is the lowest water content where the soil is in a plastic state. The water content is corresponding to a cone penetration of 2mm in the fall-cone method. The graph is shown in Figure 6. The determination of the plastic limit is made in conjunction with the determination of the liquid limit. The plastic limit increases, just like the liquid limit, during the first three weeks. The plastic limit increases with ±25% in comparison with the untreated soil. After three weeks, the plastic limit decreases and the value fluctuates between 14% and 16%.

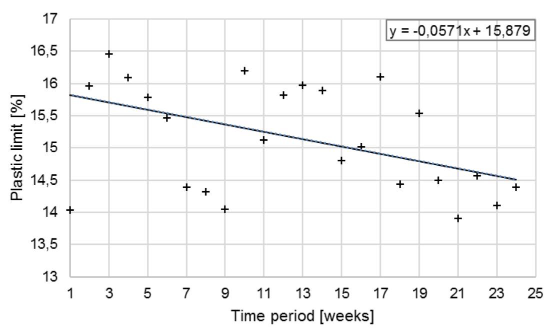



*Figure 6: Plastic limit in function of time*

The graph of the plasticity index is presented in Figure 7. The plasticity index is the numerical difference between the liquid limit and the plastic limit of the soil. The plasticity index decreased from 13,10% to 11,13%. This is a decrease of ±15% of the beginning value (13,10%). The plasticity index is decreased logarithmic until time period 20. Afterwards, the results are more constant.

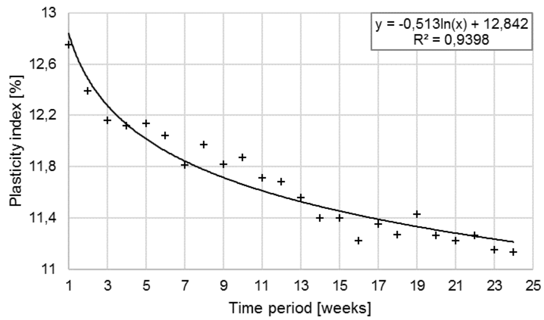



*Figure 7: Plasticity index in function of time*

Figure 8 illustrates the pH value of lime treated soil in function of time. The pH value decreases logarithmic from 12,51 to 8,12. This is a decrease of ±35%. The curve develops constant from time period 10 until time period 14, but in time period 15, the curve drastically decreases to a pH value of ±9,7. After time period 15, the pH value keeps decreasing logarithmic. The environment become less alkaline when the pH value is too low.

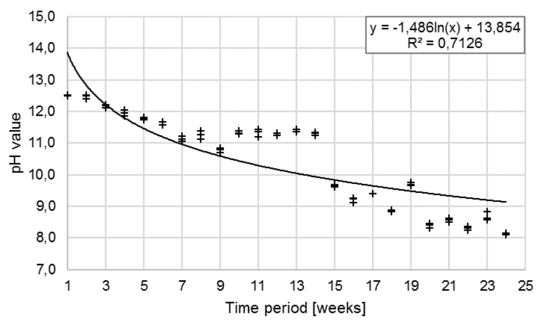



*Figure 8: pH value in function of time*

## 5 COMPARISON WITH LITERATURE

In comparison with the investigation (Chong and Kassim 2014), discussed in chapter 2, it is remarkable that both investigations become the same shape of curve. The graphs are shown in Figure 9. The compressive strength increases logarithmic in function of time in both investigations. In the research of Chong and Kassim, the compressive strength increased with ±212%, from 0,207 MPa to 0,645 MPa, in 32 weeks. In this investigation, the compressive strength increases with ±82%, from 0,476 MPa to 0,865 MPa. It should be noticed that Chong and Kassim added 10% lime to the soil and not the optimal lime content. During the first 8 weeks, the compressive strength increases the most. After 18 weeks, the compressive strength stays constant.

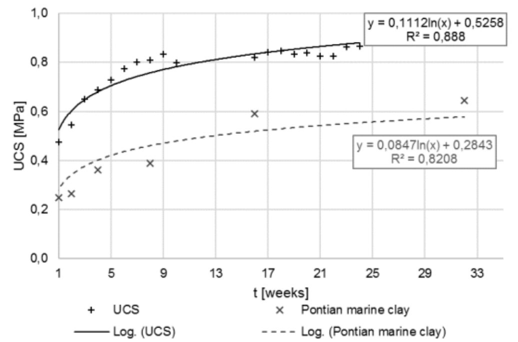



*Figure 9: Comparison with literature, UCS*

The liquid limit can be compared with the research of Krishnaiah, Ramesh and Shilpa Shet (Ramesh, Krishnaiah and Shet 2013). The graphs are presented in Figure 10. In both investigations, the liquid limit immediately increases after the addition of lime. In the research of Krishnaiah, Ramesh and Shet, 3% lime was added to the black cotton soil. The black cotton soil is a local soil which has the characteristics of a clay soil. The liquid limit of black cotton soil increased from 57,9% to 71,9% in 30 days. This is an increase of 24% of the beginning value (57,9%). The liquid limit of this investigation increases with 9% in 30 days. Afterwards, the liquid limit decreases and fluctuates around 25% and 27%.

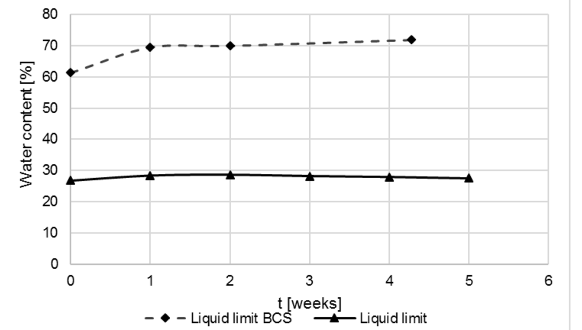



*Figure 10: Comparison with literature, liquid limit*

The plastic limit can be compared with the research of Krishnaiah, Ramesh and Shilpa shet (Ramesh, Krishnaiah and Shet 2013). The graphs are presented in Figure 11. The plastic limit of black cotton soil immediately increased with 42% after the addition of lime. The plastic limit of this investigation immediately increases with 29%. After 30 days, the plastic limit of black cotton soil increased from 25,8% to 42,2%. This is an increase of ±64% of the beginning value (25,8%). After three weeks, the plastic limit of this investigation increases with 25%, but then the plastic limit starts decreasing.

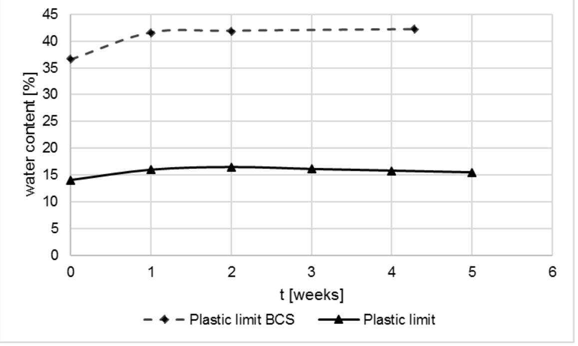



*Figure 11: Comparison with literature, plastic limit*

## 6 CONCLUSIONS

In general, the addition of lime will improve the characteristics of the soil in function of time. The compressive strength increases logarithmic, the plasticity index, the MBV and the pH value decrease logarithmic in function of time.

These results are due to the chemical reactions. These reactions were explained in paragraph 2.3. During the first weeks, the pH value is high which causes the pozzolanic reactions. As a result, the compressive strength keeps increasing, but after time period 15 or 15 weeks, the compressive strength stays constant. This can be explained with the evolution of the pH value. After time period 15, the pH value drastically decreased. As a result, the environment is less alkaline. In this way the silicon and aluminium will dissolve slower and the pozzolanic reactions become weaker. Further there will be less calcium silicate and calcium aluminate formed. These pozzolanic reactions contribute to the flocculation of clay particles. So the lower the pH value, the less pozzolanic reactions will be formed and the less flocculation will appear. This effect can be established by the MBV and the plasticity index. The MBV stays constant from time period 18 and the plasticity index stays constant from time period 20. Flocculation results into a change of structure of the soil. Because of the reduction in the plasticity of the soil, due to addition of lime, the soil becomes more granular and more workable in the field.

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