GCLs in landfill applications: influence of subgrade, temperature and confining pressure on bentonite hydration

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GCLs in landfill applications: influence of subgrade, temperature and confining pressure on bentonite hydration

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ABSTRACT

Geosynthetic Clay Liners (GCLs) are often used in landfills applications, for example in landfill covers. In order to act as a barrier, GCLs must hydrate and swell under a confining pressure. According to the French Committee for Geosynthetics, the water content of the bentonite must be at least 100% (wet dry weight). If GCLs are installed at their initial bentonite water content (around 10-15%), the question arises as to the duration of the hydration period (vapour migration from the subgrade). This question was addressed during experiments performed on a natural sodium bentonite GCL and aimed at examining the influence of several parameters: subgrade (sand versus clay), temperature and confining pressure.
Results illustrate the strong influence of the subgrade water content and grain size on bentonite water content level and hydration kinetic. As could be expected, sandy soils allow a faster hydration and higher water content than clayey soils, but results provide quantitative information on hydration duration.

1. INTRODUCTION

Geosynthetic Clay Liners (GCLs) are used in landfill liner systems in bottom, slope or cover lining applications. In order to fulfil their sealing function, GCLs need to be confined under normal stress and hydrated with water in order to achieve very low hydraulic conductivities. Initial hydration, with a non-chemically aggressive hydration fluid, is particularly important in order to confer the hydraulic performances of the GCLs subjected to a prolonged contact with leachate (von Maubeuge 1995, Ruhl and Daniel 1997, Didier and Comeaga 1997, Shackelford et al. 2000, Guyonnet et al. 2005). Indeed, the most detrimental situation for a GCL used in a landfill bottom liner system would be a direct contact with landfill leachate. Several methods for achieving this initial hydration are possible. An active process can be ensured by rainfall or controlled moistening before or after installation of the confining layer. But if GCLs are installed at their initial bentonite moisture (10-15%) and then covered by a geomembrane, as is the most common practice, there is a passive hydration of bentonite by vapour transfer of the water present in the subgrade.

In this paper we present the results of several series of tests performed to determine the stabilized water contents and hydration rates of a GCL in contact with various subgrades. The study addresses the influence of soil water content and grain size, confining pressure and ambient temperature. The GCL tested in this study was a needle-punched GCL containing 5 kg/m² of a granular natural sodium bentonite.

2. WATER CONTENT IN GCL IN EQUILIBRIUM WITH THE SUBGRADE

2.1 Testing procedure

Tests were carried out in the laboratory at T=20°±2°C on 9.5 cm diameter samples. Sample weights and thicknesses were measured before introduction into the test cell. The testing cell is a PVC cylinder with an internal diameter of 9.5 cm and a height of 30 cm.

The column is filled by successive 3 cm thick layers of compacted sand (Standard Hostun RF sand) with known water content. The GCL sample is then installed on the top of the sand. A piston allows the application of a normal stress σ=7 kPa on the GCL. Lateral sealing between the wall of the column and the piston is ensured by a silicone joint. A displacement sensor allows a monitoring of GCL swelling (Figure 1).

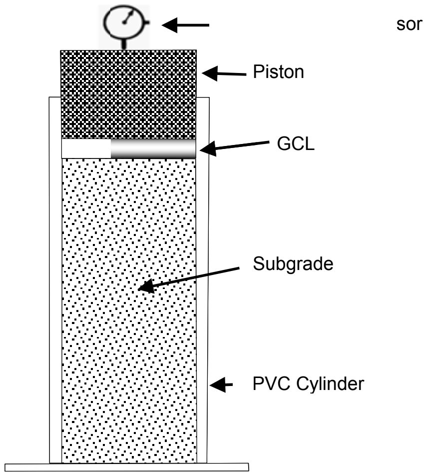

Figure 1. Apparatus for monitoring the water content in GCL in equilibrium with the subgrade

2.2 Influence of initial water content of sand on equilibrium water content

The initial water content of the GCL was w_b=10.9% and the mass per unit area 5.90 kg/m². The standard sand was used at various water contents: 3, 5, 7, 10, 12, 15 and 17%. The normal stress applied by the piston was 7 kPa for all the tests.

Once swelling had stabilized (after 24 days), water content was measured in the bentonite of the GCL. Table 1 gives the results obtained after 24 days.

Table 1. Final characteristics of the GCL

Initial water content of sand w_s (%)	Bentonite water content after 24 days w_b (%)	Swelling after 24 days S (mm)
3.0	39.2	0.36
5.0	66.38	0.87
7.0	90.66	2.34
10.0	100.7	2.58
12.0	118.7	2.62
15.0	148.4	2.90
17.0	160.6	3.46

Figures 2 and 3 illustrate the linear relationships observed between the sand initial water content (w_s) and the final bentonite water content (w_b; Figure 2) and also between the GCL swelling (S) and the bentonite water content (w_b; Figure 3) The coefficients of the regression lines depend on the nature of the subgrade or confining material and the applied normal stress.

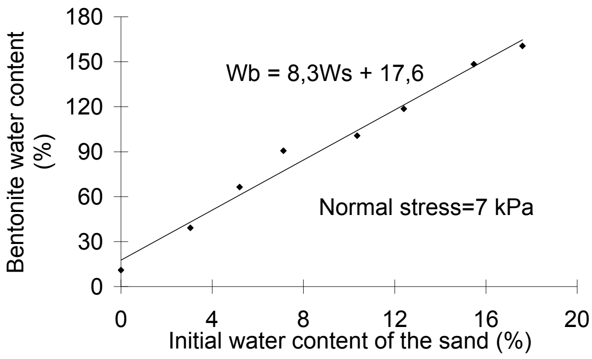

Figure 2. Final water content of the bentonite (Wb) versus initial water content of the sand (Ws).

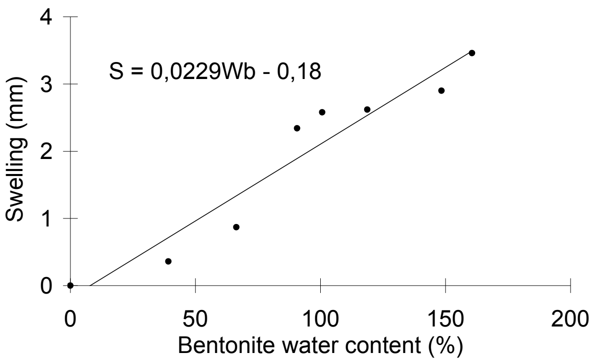

Figure 3. Swelling (S) versus water content of the bentonite (Wb).

2.3 Influence of confining pressure on equilibrium water content

The objective was to determine the influence of the normal stress σ on the stabilized water content of a GCL (w_b) in contact with standard sand. We used the same procedure as described previously but we added weights on the pistons in order to increase the applied normal stress σ.

The initial water content of the GCL was w_b=9% and the mass per unit area 4.80 kg/m^2. The soil used was standard sand with an initial water content of 7%. The samples were confined under the following normal stresses σ: 7.0, 9.9, 14.1, 21.2 and 28.2 kPa.

At the end of each test, water contents were measured in the bentonite of the GCL and in the sand at 5 regularly-spaced levels within the column. Results are shown in Table 2 and Figure 4.

Table 2. Final water content and swelling of GCL

Normal stress σ (kPa)	Bentonite water content w_b (%)	Swelling S (mm)
7.0	106.9	1.28
9.88	105.8	1.25
14.1	105.22	1.32
21.16	99.0	0.74
28.2	95.0	0.94

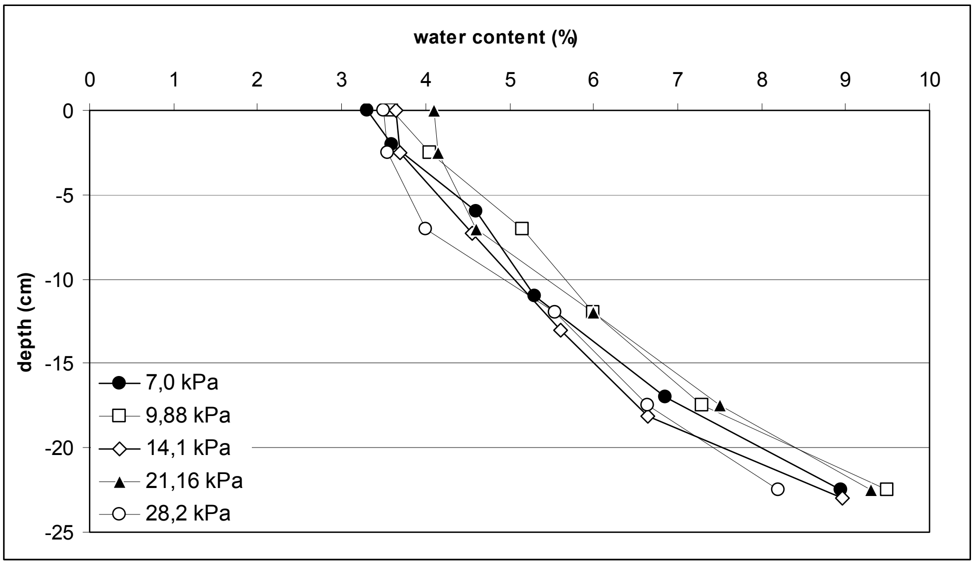

Figure 4. Water content profile in the sand column

For all the tests, the water content of the sand at the bottom of the column is higher than the initial water content (w_s = 7%) due to the influence of gravity and the low retention capacity of the sand.

A mass balance on water in the sand provides the quantity of water absorbed by the bentonite. The equilibrium bentonite water content w_b and the swelling S decreases when the normal stress σ increases (Figure 5). The water content balance decreases by about 12.5% when the normal stress increases from 7 to 28.2 kPa.

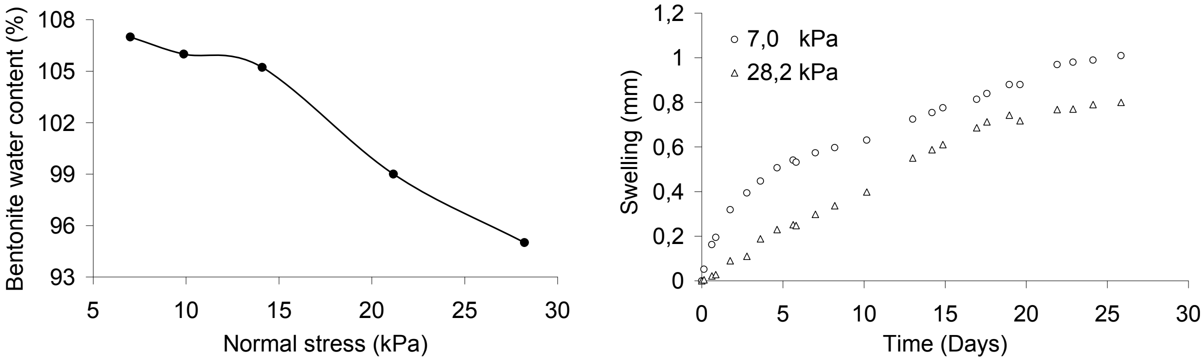

Figure 5. Bentonite water content versus normal stress (left). Swelling versus time (right)

3. HYDRATION KINETICS OF GCL ON SUBGRADE

3.1 Testing procedure

This test was carried out in a laboratory at T=5°C, 20°C and 45°C on 10 cm diameter samples. Sample and subgrade weights were measured regularly. The test cell is a sealed HDPE cylindrical container with an internal diameter of 11 cm and a height of 12 cm.

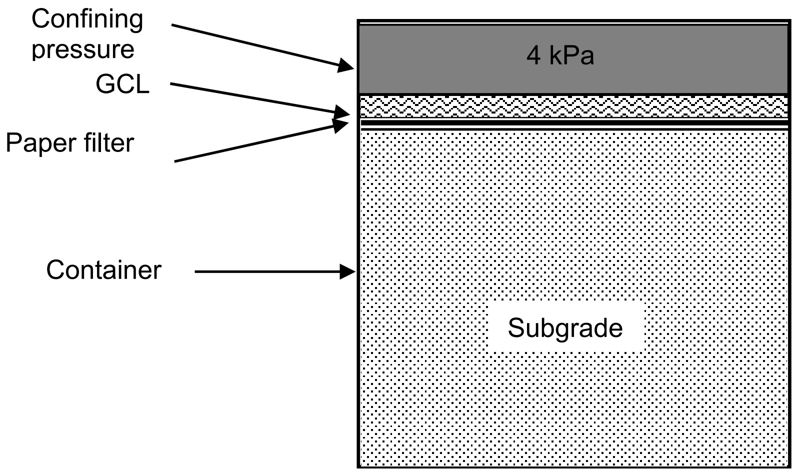

Figure 6. GCL hydration kinetics: test cell

Four subgrades were studied:
- fine grain sand at 5% and 10% water contents (wet dry weight);
- plastic clay at 15% and 25% water contents.

Cells were filled by compacting subgrades at known water contents. The GCL sample was then installed on top of the subgrade (see Figure 6). An optional steel plate allowed the application of a confining pressure on the GCL (σ=4 kPa).

3.2 Influence of water content and subgrade grain size

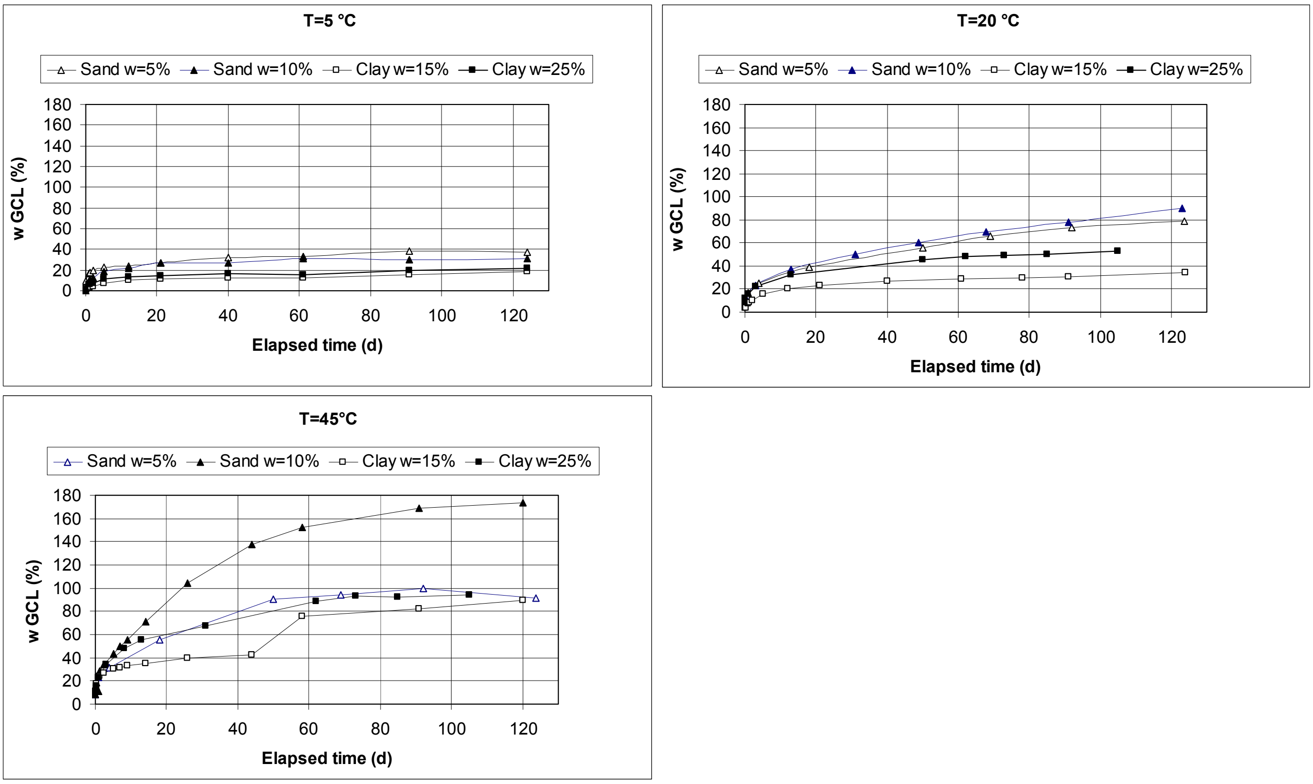

Figure 7. Influence of subgrade grain size and water content for three constant temperatures

Figure 7 shows, for a given temperature, the evolution of GCL water content w_b for each subgrade. For a given temperature, the sandy subgrade results in a higher final GCL water content and a faster hydration than the clayey subgrade, although the initial water content in the sand is lower than in the clay. At 45°C, the GCL's water content is 170% on wetter (w = 10%) sandy soil and 94% on wetter (w = 25%) clayey soil after 124 days. Open porosity of coarse grain soil is more important than clayey soil, allowing an easier vapour migration from subgrade to GCL. This shows the major influence of the retention capacity of the soil for hydration kinetics of bentonites.

Figure 7 also shows that hydration of GCLs depends on subgrade water content. As previously shown, GCL equilibrium water content is closely related to subgrade water content, while hydration rate also seems to be influenced. For a given temperature different subgrades, local slopes of hydration curves rise with subgrade water content: at 20°C, the GCL average hydration rate is 0.27% per day (%/d) for the 15% moisture clayey subgrade and over 0.50%/d for the 25% moisture clayey subgrade.

3.3 Influence of temperature

Figure 8 shows the influence of temperature T on GCL hydration. At 5°C, final water content does not exceed 40% in GCLs in contact with sandy subgrade, and 20% on clayey subgrade. At 45°C, it reaches 170% for the 10% wetted sand, whereas water content of the three other samples is about 90%. At 5°C, the equilibrium water content is reached within 30 days. At 20°C and 45°C, equilibrium is not achieved, except for the dryer sandy subgrade (w=5%).

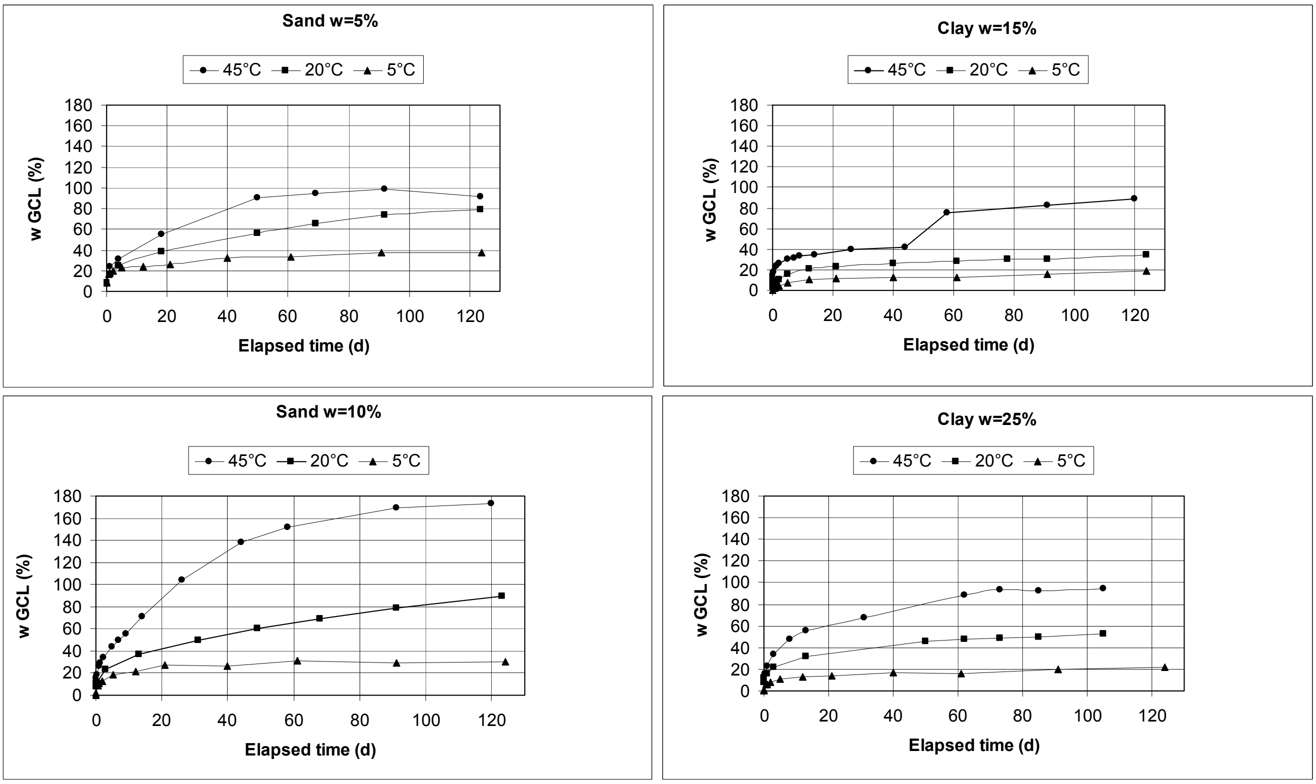

Figure 8. Influence of temperature on GCL hydration

Hydration rates are influenced by temperature, since water transfer is primarily achieved by vapour transfer. Figure 9 shows, for each subgrade, the evolution of GCL average hydration rate versus temperature. This average rate rises with temperature T, and also with subgrade grain size and water content. The measured rates are rather low, confirming that, even in good hydration conditions (wet sandy soil, high temperature), GCLs hydration is a slow process.

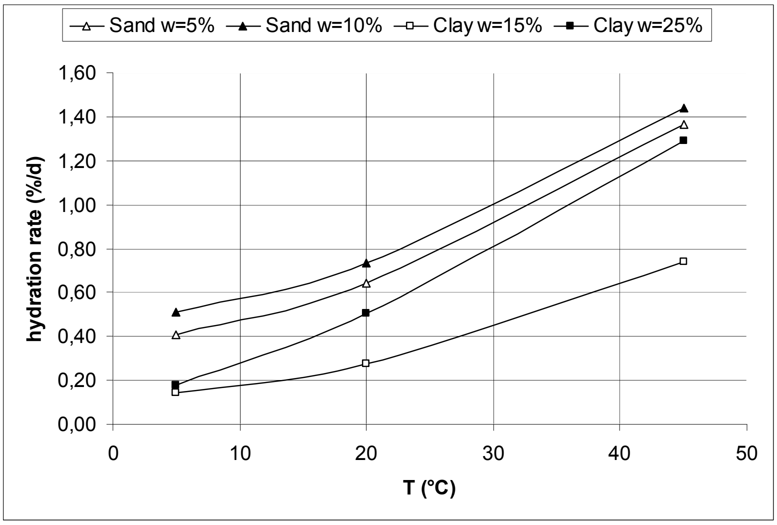

Figure 9. Average hydration rate of GCLs versus temperature.

3.4 Influence of confining pressure

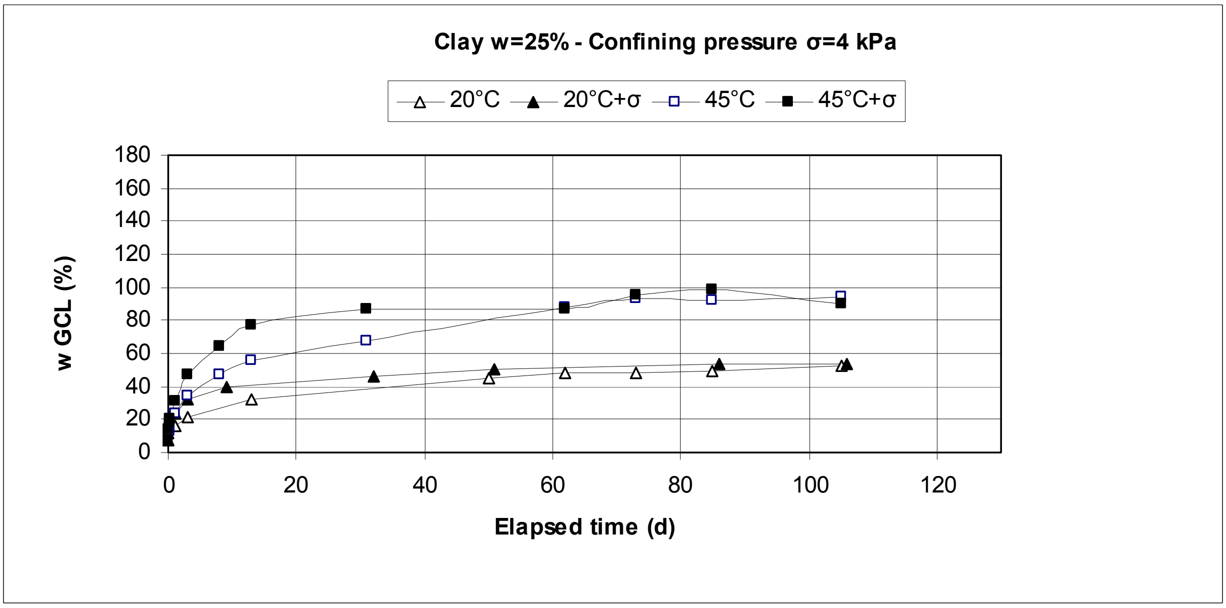

Figure 10. Influence of confining pressure on GCL hydration at 20°C and 45°C.

Consistent with results in Table 2, Figure 10 shows that confining pressure has an influence on GCL hydration. For a given temperature T, the application of a σ=4 kPa vertical stress changes slightly final water content of GCLs samples. On the other hand, confining pressure seems to be influent on hydration rate: stabilized water content is reached 30 days earlier under a vertical stress σ=4 kPa at 45°C.

4. CONCLUSIONS

The results of this study show that hydration of GCL by subgrade water requires periods of time on the order of several weeks. Results also suggest that both final water content and hydration rate of GCLs increase with subgrade grain size, subgrade initial water content and temperature. Final water content decreases with confining pressure, whereas hydration rate rises. The minimum water content of 100%, sometimes recommended in geotechnical guidelines, is reached for coarse grain subgrades (sand) or high ambient temperatures (45°C). Such conditions are not typical of European landfills, where subgrades are mostly fine grained soils (typically clays and loam) and temperatures are colder.

This study is by no means exhaustive, as it concerns only one type of GCL and tests were performed for a limited number of hydration conditions. Further studies should examine a larger range of GCLs (with different types of bentonite mineralogy or grain size, different geotextiles, etc.), and of subgrades (silts, marls …).

However, some recommendations can be proposed based on the results obtained. Firstly, particularly under desiccating climatic conditions (due to heat or wind), subgrade water content should be controlled and possibly maintained by sprinkling, until the GCL is installed. Then, GCLs could be hydrated before geomembrane implementation. Didier et al. (2009), show that the hydraulic conductivity of a needle punched GCL is not reduced when the GCL is hydrated with sprinkling hydration without confinement. Finally, confining pressure (drainage layer) should be implemented as fast as possible, in order to speed up GCL hydration.

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