Abstract

Geosynthetic clay liners (GCLs) are widely used to isolate waste disposal facilities in order to prevent pollutant migration into the ground. GCLs are factory-manufactured hydraulic barriers containing a thin uniform layer of bentonite sandwiched between two geotextile or glued to a geomembrane. Bentonite is used as barrier material thanks to its low conductivity to water. However, the hydraulic performance may be impaired by contact with aggressive liquids due to cation exchange and highly concentrated solutions. The efficiency of these liners can further deteriorate if hydration with an electrolyte solution is combined with wet and dry cycles, as a result of seasonal changes in temperature, rainfall and groundwater migration.

The purpose of this study was to evaluate the effect of wet and dry cycles with seawater on a modified bentonite, HYPER clay. Seawater was selected to simulate conditions where wet-dry cycling is associated with high ionic strength of the inorganic permeant solution, such as a leachate. It represents an aggressive environment for the bentonite clay double layer thickness as it contains a high amount of monovalent and divalent cations. HYPER clay is a polymer amended bentonite with enhanced performance in presence of electrolyte solutions thanks to the irreversible adsorption of the polymer onto the clay.

To study the effect of wet and dry cycles a number of tests was performed. The swelling ability was evaluated by means of free one-dimensional swell tests, swell pressure tests, temperature impact tests and μCT scanning. Whereas the hydraulic performance is studied through hydraulic conductivity tests with flexible wall permeameters. The influence of drying temperature on the swelling and hydraulic performance was also investigated.

Firstly, the thesis includes a description of the main polymer-modified bentonites developed so far. An overview of the hydraulic performance of these materials is provided. The amendment with polymers improved the barrier performance of the bentonite compared to untreated clay. However, the polymer is not always intercalated in the clay structure. Therefore, release of the polymer was experienced in some cases.

The hydraulic conductivity and swelling ability of powder HYPER clay subjected to wet dry cycles with seawater was studied. The performances of HYPER clay were compared with those of untreated sodium bentonite. The swelling ability was quantified by means of free one-dimensional swell tests. The treatment with the anionic polymer improved the swelling and sealing ability of the bentonite subjected to six wet and dry cycles with seawater. The swelling of HYPER clay treated with 8% of polymer at the end of the cycles was comparable to the maximum swelling of untreated bentonite in deionized water. In addition, μCT analysis demonstrated the better self-healing capacity and the smaller volume of cracks of HYPER clay compared to untreated bentonite. Unlike the untreated clay, HYPER clay maintained low permeability to seawater throughout the cycles.

The impact of three different drying temperatures (air, $40°C$ and $60°C$) on the self-healing capacity, swelling ability and water adsorption of HYPER clay and untreated clay was investigated using oedometer cells. These results were then adopted to interpret the hydraulic conductivity of GCL prototypes previously subjected to wet and dry cycles at different drying temperatures ($40°C$, $60°C$ and $105°C$). In addition, the impact of wet and dry cycles on the GCLs overlap was evaluated by means of the flow box. The flow box allows the measurement of a large scale sample and it is possible to check the permeability in different sections of the sample surface.

The swelling ability and water adsorption of HYPER clay always exceeded the values recorded for the untreated clay independently of the drying temperature. The higher swell of HYPER clay suggests a better hydraulic performance compared to untreated clay. Indeed, the hydraulic conductivity to seawater after four wet and dry cycles of the GCL containing the polymer treated bentonite was lower compared to the GCLs containing untreated clay at each drying temperature. These findings demonstrated the persistence of the polymer in the bentonite structure. The HYPER clay treatment intercalates the polymer in the interlayer region of the bentonite, likely inducing a disperse structure of the bentonite.

Swell pressure tests were conducted to measure the swelling ability of both untreated clay and HYPER clay through four wet and dry cycles with seawater at a drying temperature of $40°C$. Untreated bentonite was also subjected to wet and dry cycles with NaCl solution. HYPER clay confirmed its higher swelling ability even in presence of an aggressive environment, i.e. seawater. These results were interpreted theoretically with the model developed by Dominijanni and Manassero (2012a,b). The theoretical curves were drawn based on the swell pressure of untreated bentonite and HYPER clay 8% to increasing ionic strength. The assumption of constant number of platelets per aggregate independently of the ionic strength was adopted to obtain acceptable estimations of the experiments performed. This first interpretation demonstrated that the polymer treatment increased the net negative charge of the clay and limited the aggregation between clay platelets with a consequent improvement of the swelling ability. The swell pressures values through wet and dry cycles with sodium chloride and seawater were then back analyzed.

The results obtained from wet and dry cycles with sodium chloride of untreated clay showed that it might be possible to use the model to simulate the aging process. On the other hand, more investigation is required for the samples subjected to the cycles with seawater due to the lack of information about the final concentration.

The back analysis of experimental literature data allowed to define the fixed charge concentration for modified bentonites (BPN and DPH GCL) extending the application of the model to all treated clays. Results of chemico-osmotic tests on BPN and DPH GCL specimens, hydrated with KCl, were used. In general, values of membrane efficiency for modified bentonites were higher than those of conventional bentonite specimens tested with KCl solution. The theoretical curve of the global reflection coefficient versus average concentration represented well the experimental results from both, BPN and DPH GCL. As for untreated bentonite, the membrane efficiency of modified bentonites increased with decreasing the porosity of the specimens. The comparison of the solid skeleton electric charges showed higher value for BPN compared to DPH GCL, probably due to the higher amount of polymer. However, the solid skeleton electric charges of the modified bentonites were higher compared to those of untreated bentonite likely due to the presence of the polymer.