Technical Workshop on Reinforcement and Drainage in Soil Structures. June 2024, Barcelona.
Technical Committees on Soil Reinforcement (TC-R, IGS) & Hydraulic Applications (TC-H, IGS), and
Reinforced Fill Structures (TC-218, ISSMGE)
Session: ***Geosynthetic materials and soil interaction***

A NEW LOOK AT THE USE OF COATED PET GEOGRID REINFORCEMENT IN HIGHLY ALKALINE ENVIRONMENTS

Samuel R. Allen

TRI Environmental Group
Headquarters: 9225 Bee Caves Rd., Austin, TX 78733, USA
E-mail: sallen@tri-env.com, web page: https://www.tri-env.com

Keywords: Soil reinforcement, Reinforced fill structures, PET

Abstract: *It has historically been assumed that coated polyester geogrids are not suitable for applications where the pH of the soil around the geosynthetic is greater than 9. These applications primarily include cohesive soils treated with lime, or ground hardened concrete or cement mixtures. The pH of these admixtures is often suggested to be in the range of 11-12 but actual field data are difficult to locate. However, it is known that a target pH of greater than 12.4 is used when clayey soils are stabilized with hydrated lime. Another environment of high pH is freshly cured concrete, which is reported to have a pH of greater than 12. There is a new interest in looking at the hydrolysis behavior of coated PET geogrids at pH levels greater than 9. This effort is buoyed by some of the limitations of the work previously done on this topic.*

1 INTRODUCTION

It has long been recognized that poly(ethylene terephthalate) (PET) has a different mechanism for hydrolysis, depending upon the pH of the solution (2-6). In pH solutions of 9 and below, water is adsorbed by the PET fibers and hydrolysis takes place throughout the entire thickness of the fibers. In higher pH solutions, however, base-catalyzed hydrolysis occurs on the outer surface of the fibers and the PET is hydrolyzed, then eroded from the surface. The result is that the remaining material retains its original properties even though the fibers are getting smaller and smaller. This occurs this way because ions are too large to permeate polymers. Therefore, only the accessible part of the fiber reacts with the hydroxide ions.

2 ALKALINE CHEMISTRY

The chemistry of alkaline solutions needs to be considered when performing hydrolysis experiments or contemplating the long-term performance of PET coated geogrids. This was pointed out in a review article by Van Shoors (Shoors, 2007). The most important aspect is the reaction of any metal-hydroxide solution with atmospheric carbon dioxide. Examples for $NaOH$ and $Ca(OH)_2$ are shown below (Eqs. 1 and 2):

$$2NaOH + CO_2 = Na_2CO_3 + H_2O \tag{1}$$

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O \tag{2}$$

Equation (1) shows that sodium hydroxide is converted to sodium carbonate. This is important because sodium hydroxide is a strong base while sodium carbonate is a weak base. The weak base would be far less reactive towards PET. Secondly, since they are both bases, the pH would not show a dramatic change during this conversion. For example, the pH of a 0.1N solution of sodium hydroxide is 13.0 and the pH of a 0.1N solution of sodium carbonate is 11.6. If 75% of the sodium hydroxide was converted to carbonate, the pH would still be around 12.4. Therefore, the conversion from a strong base to a weak base is difficult to detect by a simple pH measurement. Equation (2) shows the reaction between calcium hydroxide (hydrated lime) and carbon dioxide. In this case, it is possible to detect this reaction because the product, calcium carbonate is insoluble in water. Therefore, a white precipitate is formed when carbon dioxide is present. This chemistry makes hydrated lime a very good carbon dioxide trap and some have proposed this reaction as a way to reduce CO2 emissions into the atmosphere. These reactions need to be considered in the context of the long-term performance of coated PET geogrids. In some cases, like fresh concrete, there will be a high, yet rapidly declining pH. In other applications, like lime treated soil, there will be a more constant high concentration of calcium hydroxide.

3 FIELD STUDIES

Wan et.al. (Wan, 2013) measured pore water pH values in curing concrete before and after atmospheric carbonation. They showed that the pH could drop from over 13 to around 8 as a result of CO2 exposure. Roadcap et.al. (Roadcap, 2005) reported calcium carbonate (calcite) deposits up to four inches deep in wetlands near closed steel mills in the Lake Calumet region of Chicago caused by atmospheric carbonation. They also proposed air sparging as a way to treat high pH solutions.

Two papers were found that showed the pH in aqueous solutions near poured concrete. The first was a Research Note from the Oregon Department of Transportation (ODOT, 2003). The pH of water in a drainage ditch near a freshly poured foundation shaft. Measurements were made right after the pour and 31 hours later. The results within a few feet of the shaft showed a maximum pH of 10.4 right after the pour and a pH of 8.2 at the same location 31 hours later. A location several meters from the shaft peaked at 9.6 and was down to 7.3 after 31 hours. This shows how quickly the pH can change from water dilution and atmospheric carbonation. Thomle (Thomle, 2010) studied the pH of water exposed to pervious concrete. He showed many results from many sites obtained over a period of several years. The main conclusion of this study was in the majority of cases, the pH of waters near pervious concrete is around pH 9 in two years.

And finally, three papers were published by the Geosynthetics Institute (Koerner, 2002, 2003, 2005) where pH measurements were taken at the geogrid-block face interface of Segmented Retaining Walls. The first two involve the same test wall. The wall included three different manufacturers of blocks and pH measurements were taken between the blocks and the geogrid for over 2 years time. The results showed that at the beginning, the pH of the three blocks were 10.5, 10.0, and 9.2. After two years, the values had dropped to 8.8, 8.7, and 8.3. The results showed that within two years, the pH was less than 9.0 for all three of the tested materials. Incidentally, only the pH was measured. It is not known how much of the solution was calcium hydroxide and how much was calcium carbonate. The third paper reported the results of pH measurement taken on 25 different retaining walls in 7 different states in the US. The ages of the walls were from 0.5 to 8 years and measurements were made only a single time. The results showed that two walls were 9.0 or greater (9.4 and 9.0), two walls were between pH 8.0 and 9.0 (8.2 and 8.0) and the other 21 walls had pH values less than 8.0. Again, it has been shown that the pH near cured concrete is not very high.

4 BENCH SCALE LABORATORY TESTING

A simple beaker experiment was conducted that measured CO3 and OH ions using two indicators: Phenolphthalein (ph 8-9) and Methyl Orange (pH 3-4). Differential titration was performed to track hydroxide ions as a function of stirring. Figure 1a shows the concentration of OH ions present after stirring for 28 hours. An additional laboratory test employed a small tank with a recirculation pump. The sample approach was followed. Figure 1b shows the test results.

5 COATING AND OTHER DESIGN FEATURES

A Types of coatings used on currently produced PET geogrids includes Poly(vinyl) chloride (PVC), Polyethylene (PE), Poly(vinyl) alcohol (PVA), Ethylene Vinyl Acetate (EVA), Styrene Butadiene Rubber (SBR), and Bitumen. This list is probably not complete but the point is there are many different coating types which will dramatically affect the long-term performance of these products. Most, if not all, of these are more resistant to the effects of high pH than the PET alone, so the coating will definitely delay the onset and minimize the severity of the hydrolysis reaction.

One may argue that looking at only the uncoated fiber properties is the most conservative approach. However, the coating type and its application is one area where a superior producto is only observed by testing it in its final, coated, form.

In terms of resistance to hydrolysis, there have not been many papers that have addressed this. In the landmark paper on this topic in the USA (Salman, Elias, 1997) a coated producto did show the lowest rate of hydrolysis in water (pH = 7). The coated product also had a lower rate of strength loss in pH=12. The uncoated product lost 4.1%/year while the coated producto lost 1.6%/year. The two polyesters had the same molecular weights, but the coated fibers were thicker (21 vs. 17 µm) while the uncoated fibers had a lower CEG value (18 vs. 27 meq/kg). Jeon et al. (Jeon, 2005) compared an acrylic coated grid to a PVC coated grid and concluded the PVC coating offered superior protection. However, the results were not compared with an uncoated product and there were few details about how the test specimens were prepared.

Besides the type of coating, there are many different constructions of PET geogrids. Some products consist of straight fiber bundles while others have twisted or knitted fiber bundles. There are also products in which individual bundles are coated and impregnated with the coating before the final product is constructed while others are produced first and then coated. Some coatings are much thicker than others. Experience from laboratories has shown these products to be extremely difficult to dissolve for CEG and viscosity (molecular weight) testing. When one combines all the different coatings with all the different constructions, the variability in hydrolysis resistance may be expected to vary. However, it is also quite likely that many of these products are far more resistant to the effects of high pH than the bare PET fibers.

6 CONCLUSIONS

- Field studies indicate that high pH is not encountered very often and when it is, if atmospheric CO_2 is present, the chemistry rapidly changes and becomes much less aggressive.

- Except in the case of hydrated lime modified soils, where the pH is targeted to be 12.4, a highly alkaline environment is just not likely for the other civil engineering applications.
- Bench-scale testing suggests that carbonation chemistry is very fast when air or aerated water (partially saturated) conditions exist.
- Final products should be tested for hydrolysis resistance.

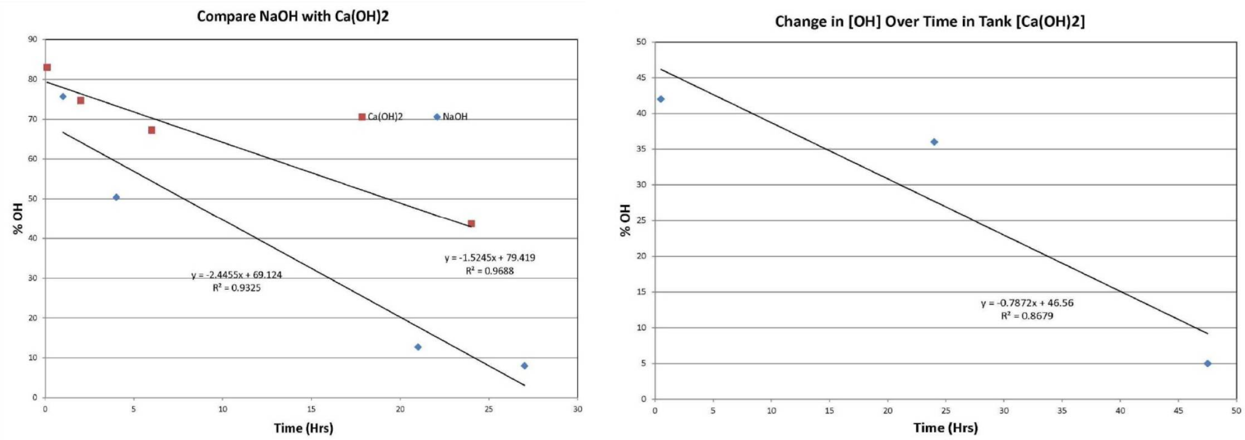

Figure 1: Percent hydroxide ions present: (a) after stirring (NaOH vs $Ca(OH)_2$) and (b) after circulation ($Ca(OH)_2$).

REFERENCES

Van Schoors, L. Vouyovitch. "Hydrolytic aging of polyester (polyethylene terephthalate) geotextiles: state of the art assessment."+ Bulletin des Laboratoires des Ponts et Chaussées 270: 271 (2007).

Wan, X., Whitman, F. H., et.al., “Chloride Content and pH Value in the Pore Solution of Concrete Under Carbonation,” J. Appl. Phys. & Eng., 14(1), pp. 71-78 (2013).

Roadcap, G.S., Kelly, W.R., and Bethke, C.M., “Geochemistry of Extremely Alkaline (pH > 12) Ground Water in Slag-Fill Aquifers,” Ground Water, Vol 43 (6), pp.806-816 (2005).

Oregon Dept. of Transportation, “The pH of Water in Contact with Fresh Concrete,” Research Notes, RSN 03-02 (2003).

Greenwood, J.H., “Creep, Stress Rupture and Hydrolysis of Polyester Geogrids,” Geo Report No. 37, Geotechnical Engineering Office, Civil Engineering Dept., Hong Kong (1993).

Thomle, J. N., “The Declining pH of Waters Exposed to Pervious Concrete,” MS Thesis, Washington State University (2010).