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The Impact of High-Concentration Salt Solution on Morphological Changes in a Geosynthetic Clay Liner

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ABSTRACT

Microscopic examination was used to begin investigating the changes in geosynthetic clay liner (GCL) specimens that had been hydrated with two separate solutions: pure water and a 50 percent concentration NaCl solution. After already being hydrated with NaCl aqueous solution, the GCL samples were examined under an electron microscope. Even though the treated GCL samples' surfaces mirrored those of the untreated GCL, a crystal deposit was found there. It was found that the bentonite particles in the GCL sample appeared more solid after being hydrated with distilled water as opposed to the NaCl solution using a scanning electron microscope (SEM). It seems that wetting the salt solution decreases the bentonite particles' tendency to swell. Additionally, it was demonstrated by the energy-dispersive X-ray spectrometer (EDS) data that distilled water hydration had no impact on the distribution of the elements identified in the GCL samples. On the other hand, the presence of bound chlorine demonstrated that the bentonite particles had absorbed the NaCl solution. The hydrated GCL sample's hydraulic conductivity showed some variation as well.

INTRODUCTION

The most popular way of disposing of solid waste around the world is still landfilling (Ludwig et al. 2002, Feng et al. 2004). Solid trash will begin to break down in landfills and produce leachate. (Justin 2000). Leachate is difficult to manage because it contains varying amounts of physiochemical components, pathogens, and heavy metals. (Daud et al. 2009, Mohajeri et al. 2010, Li et al. 2010, Foul et al. 2009, Palaniandy et al. 2010, Renou et al. 2008). If landfill effective organizational performance escapes and contaminates the environment, such as groundwater, there might be serious environmental and health consequences (Tian et al. 2016, Ruhl & Danirl 1997, Liu et al. 2015). The capability of landfills to serve as a hydraulic barrier to halt leaks or as an ideal place for leachate collecting (Hu et al. 2002, Jingjing 2014, Kalka 2012, Benfenati et al. 2002, Du et al. 2009, Chen et al. 2008). Leachate containment is therefore the most important purpose of landfill design and construction. (Yesiller Shackelford 2010) to lessen a landfill's negative effects on the environment and public health.

To minimize the environmental footprint of landfill leachate, landfills are fitted with just an impervious bottom liner to protect effluent from contamination located near groundwater (Justin 2000, Alex et al. 2016). To prevent leachate intrusion, landfill firms typically install an impermeable soil layer at the bottom of a landfill, such as a compacted clay liner (CCL). In developed nations, besides that, geosynthetic liner (GCL) rather than clay-based liner has been used as a liquid waste barrier (CCL). Due to the GCL's superior advantages in terms of availability, transit, ability to handle, assembly, and affordability, it has eclipsed the CCL (Yesiller & Shackelford 2010). Once GCL is formed, it usually consists of two geosynthetic layers wedged together by bentonite, which, once hydrated, continues to expand and becomes impenetrable. The degree of hydration, temperature, and permeable liquid all have an impact on how permeable the geosynthetic layers are (Thammathiwat & Chim-oye 2010, Alex et al. 2022, Lake & Rowe 2000, Barclay & Rayhani 2013) as well as liner configuration, such as single or composite lines that contain geomembranes (Jingjing 2014, Bowders 2010).

The capacity of GCL to achieve maximal hydraulic performance depends on the saturation level. The liner system needs to be adequately hydrated for GCL to prevent liquid pollutant leaks (generally with water) (Bowders 2010). The flecks of bentonite in the GCL tend to expand and bind together as a result of hydration. The hydration process starts as soon as the GCL is placed over a subgrade, such as damp soil. Because the subgrade is already moist, no water needs to be added to the GCL. When the GCL begins to hydrate, it collects water from the subgrade, grows in size, and eventually becomes moisture-resistant. As an effluent barrier, the GCL must interact with leachate, which may encompass organic substances, toxic substances, and inorganic materials (Kolstad et al. 2014, Petrov & Rowe 1997). Ionic species from acid and basic earth metals, such as Na^+ and Ca^{2+} ions, are present in large amounts in the leachate from landfills that store solidified or stabilized inorganic hazardous waste (SIHW). According to many flow-through leaching measurements, the Na^+ and Ca^{2+} ion content in this type of SIHW is typically somewhere between 1000 and 2000 $mg.L^{-1}$. for the first several pore quantities of flow (Poon et al. 2001, Chen et al. 2015). Several studies have been conducted to investigate the association between the hydraulic conductivity of GCL and the surface runoff of inorganic salt solutions (Kolstad et al. 2004, Petrov & Rowe 1997, Xue et al. 2012, Alex et al. 2022). It was discovered that the permeability of GCL changed whenever the solution contained a heavy amount of NaCl or a significant amount of ions. Furthermore, when the GCL was pervaded with small concentrations of NaCl solution, the hydraulic conductivity was noticed to be identical to the permeability of tap water or DI water (Lee & Shackelford 2005). Long-term permeation with a supersaturated NaCl aqueous solution produced a tremendous rise in the capillary pressure of the GCLs (Jo et al. 2005).

This investigation aimed to address the morphological alterations in GCLs as a continuation of earlier research findings. It does this by doing initial research from a microscopic perspective, therefore making it easier to understand how salt solution affects GCLs. In this study, the seepage fluid was a 50 percent concentrated NaCl solution.

MATERIALS AND METHODS

In this investigation, two different kinds of prepared GCL samples from two separate sources were examined. All of the samples contained sodium bentonite; the samples of bentonite powder were designated by the letter "P" on the label, while the samples of granular bentonite were designated by the letter "G." Then, using distilled water and salt, solubilized NaCl solutions with a concentration of 50% were produced. The subscript on the sample labeling denoted the sample condition. The existing GCL specimens (dry) have been labeled with just an "O," whereas the samples marked with "W" have been hydrated with distilled water and the samples marked with "N" have been hydrated with NaCl solution (Table 1). As previously mentioned, microscopic imaging was employed to study the GCL samples (Fig. 1), as well as a scanning electron microscope (SEM) (Fig. 2), which was used to look at the bentonite particle size and sample morphology (JEOL-JSM-IT 200 with EDS). The samples were placed in a high vacuum chamber and subjected to a 15 kV analysis, followed by an XRD examination to identify the elements. The element composition was examined using XRD, and the resulting numbers are shown in Fig. 3.

RESULTS AND DISCUSSION

After hydration for two weeks, the GCL samples were baked to remove the moisture content. Any physical alterations were examined using optical microscopy both before and after hydration. The physical appearance of samples having IDs of P-O, G-O, P-W, and G-W shows no difference. It shows that hydration with distillate water had no impact on GCL samples after drying. Meanwhile, in P-N and G-N samples, some crystal particles were found on the top layer of betonies; these are all the dried forms of NaCl crystals.

Morphology and Characterization of Samples

The GCL samples were again investigated for their shape and mineralogy using a scanning electron microscope (SEM). SEM images exhibit the liner member binding characteristics; they were used to absorb the physical changes due to inner particle interaction due to hydration. Fig. 2 shows the morphology of GCL samples, which illustrates the images of the sample particles when they are dry and later hydrated by distilled water and the NaCl solution. The sample P-O, and G-O in Fig. 2 shows bentonite before it has even been hydrated with any particular solution. The samples with P-O and G-O labels contain powder as well as granular bentonite, respectively. The particle clods inside the bentonite powder were larger and denser than those inside the granular bentonite particles, as shown in an analysis of the SEM image.

The distilled water hydrated samples of P-W and G-W show that the hydration process causes particle clods flocculation; it forms more solid bentonite particles, and the surface appearance shows that the particles have well-fitting

Table 1: GCL sample ID.

Sl.No	Sample code for microscopic examination	Bentonite type	Hydration condition
1.	P-O	Powder	Dry
2.	G-O	Granular	Dry
3.	P- W	Powder	Distillery water
4.	G- W	Granular	Distillery water
5.	P-N	Powder	NaCl
6.	G-N	Granular	NaCl

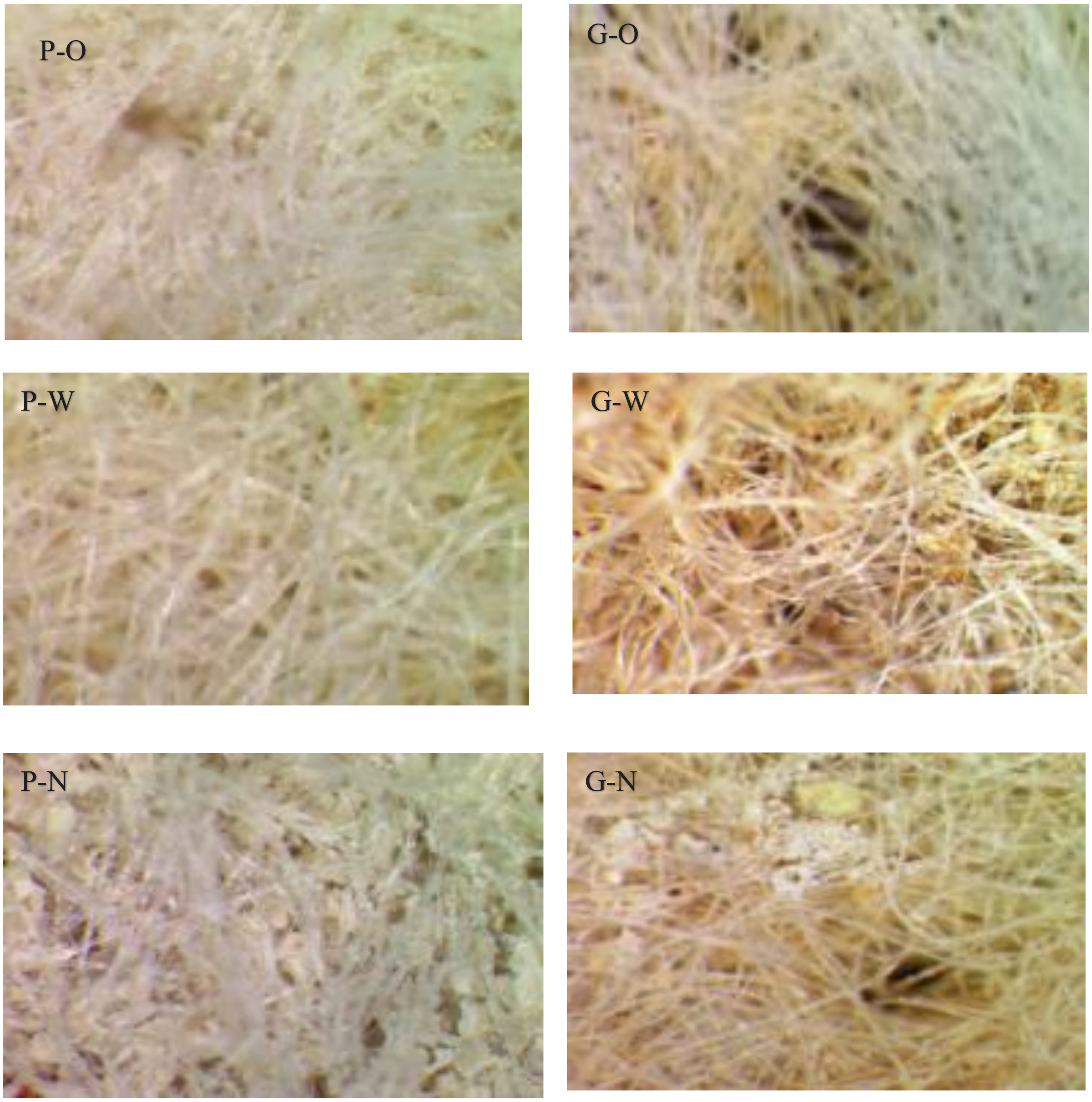

Fig. 1: P-O, G-O- preliminary state of the GCL; P-W, G-W - GCL samples hydration with distilled water; P-N, G-N- GCL specimens hydrated with NaCl solution.

attachments. As a result, hydrating bentonite with distilled water serves to decrease the voids between internal particles. Instead of the particles' structure and crystallography, the bentonite particles are significantly affected by the hydration of the material used in distilled water.

Fig. 2 depicts the morphology of hydrated bentonite molecules in a highly concentrated (50%) NaCl solution, labeled P-O and G-O, which exhibit blade-type crystal particles and crusted irregular particles, respectively. P-W and G-W both have crusted fungus-like structures with high densities and irregular elliptical-shaped particles. Here we found that the arrangement of particles and interaction between the particles were observed, and it was found that they were entirely different from distilled water-hydrated specimens. The bentonite particles are more clustered and have high swelling. As a result, it is reasonable to believe that the highly concentrated concentration of solute can alter the reaction of bentonite particles. An X-ray diffraction spectrometer was used to quite successfully investigate the impact that hydration with alternative approaches had on both types of bentonite particles (EDS). The distribution of elements within every sample was then calculated.

The existing chemical compositions of bentonite in the two distinct forms of powder and granular throughout GCL are shown in Fig. 3. When examined using XRD at a bearing angle of 2θ, it was noticed that bentonite contained silica (Si), aluminum (Al), and iron (Fe), as well as other elements of the sum alkali group. The same minerals were discovered here, with quartz, mullite, and hematite being the three crystalline phases identified with different oxidation forms, silicates (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), and calcium oxide (CaO) being the major elements at 66.72%, 16.73%, 3.26%, and 1.46%, respectively, while minor alkali group elements such as magnesium (Mg), sodium (Na). Similarly, in this phase, after hydrating bentonite with distilled

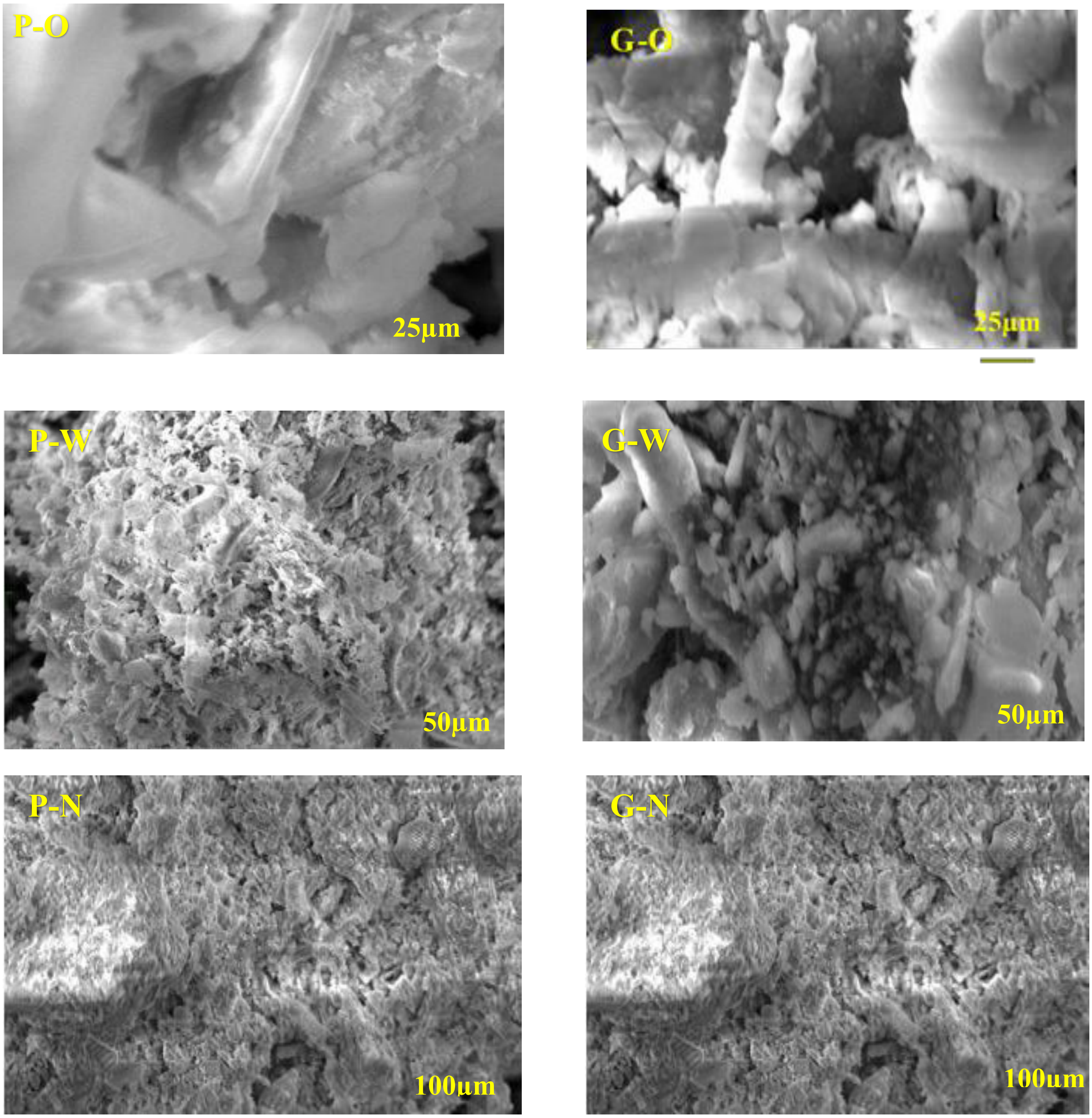

Fig. 2: SEM image of the bentonite particles: P-O, G-O: Before hydration; P-W, G-W hydrated with distilled water; P-N, G-N: hydrated with NaCl solution.

water, P-W and G-W specimens discovered the same element spreading. It should be demonstrated that no water content has been observed in any of the specimens upon oven drying, indicating that H_2O acted only as a supplement in all mixers.

The XRD humps of P-N and G-N show the element distribution of bentonite particles after the hydration of a highly concentrated (50%) NaCl solution. In this stage, the high amount of sodium chloride particles was absorbed, and

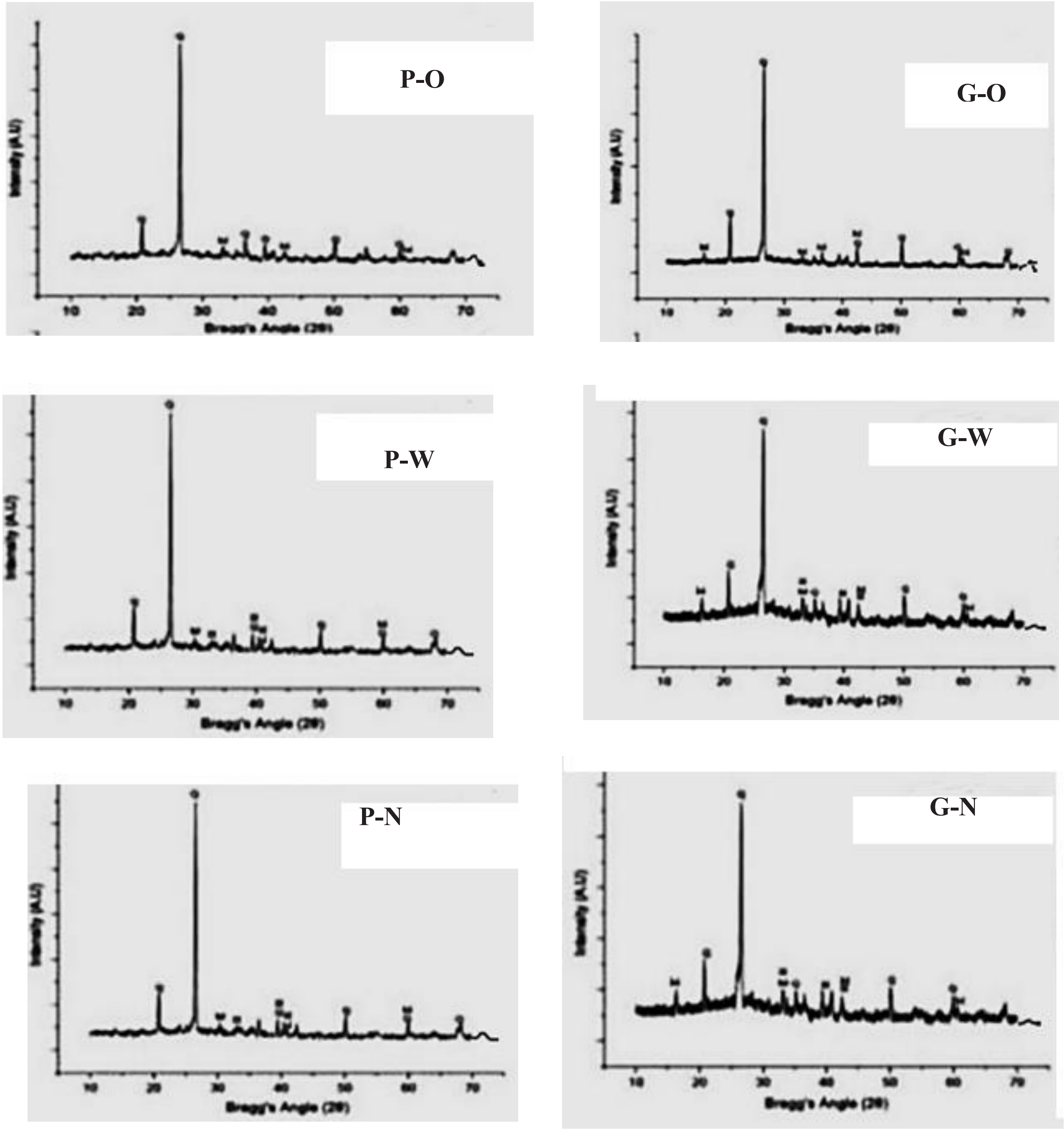

Fig. 3: ERD humps of the bentonite particles: P-O, G-O: Before hydration; P-W, G-W hydrated with distilled water; P-N, G-N: hydrated with NaCl solution.

it appeared with a brighter color in the SEM image, along with a small surface of bentonite. It was determined that only small modifications in the bonding structure of the bentonite particles had occurred; also, a highly concentrated NaCl solution significantly reduced the amount of CaO and MgO in the samples. Increased NaCl concentration can help carbonate minerals dissolve (Lee & Shackelford, 2005). This effect was observed in both granular and powder bentonites.

The Impact of Hydraulic Efficiency

The amount of water that is applied to the bentonite surface sandwiched between the two geotextiles determines its permeability (Lee & Shackelford 2005). The incompatibility of GCLs' permeability affects their performance since they are utilized as leachate barriers through landfill liners, and this is a significant issue during the landfill design phase. As a result, this study also evaluated the hydraulic performance of GCLs when they were hydrated with all these types of permanent solutions, distillate water, and NaCl. The outcomes are shown in Fig. 4. The current study, as previously stated, furthermore explored the effectiveness of using a GCL as an equitized protective layer in the presence of NaCl in the seeping solution to evaluate the influence of different types of effective alternatives on a moisturized GCL. Both GCL samples' hydraulic conductivities were determined to be 1.41 x 10^{11} m.sec^{-1} and 7.64 x 10^{11} m.sec^{-1}, respectively. Meanwhile, the highly concentrated NaCl (50%) solution has very slightly modified the permeability of GCL and tends to increase the permeability because the addition of minerals and salts to water can weaken this same adhesion strength of bentonite while increasing permeability. According to the majority of other researchers' findings, the hydraulic permeability of clay increases with increasing concentrations of inorganic sodium chloride (Lee & Shackelford 2005). Meanwhile, the mineral loss causes the bentonite skeleton to end up losing and weakening the connection between molecules so that high concentrations of NaCl help improve permeability behavior. The hydraulic conductivity of samples P-W and G-W, on the other hand, is 1.39 × 10^{-10} m.sec^{-1} and 1.96 × 10^{-10} m.sec^{-1}, respectively.

CONCLUSION

The main aim of the study was to examine the morphological changes of a geosynthetic clay liner in a highly concentrated salt solution. The laboratory tests show that using bentonite in conjunction with a geosynthetic clay liner improved particle properties while decreasing hydraulic conductivity. The following conclusions should be drawn from this experiment:

- According to the optical microscope analysis, the GCL samples appear to have remained unchanged after being hydrated using distilled water and then dried. When highly concentrated NaCl (50%) was used as the hydration solution, crystal deposits were discovered on both the bentonite surface as well as the geosynthetic cover.
- The surface morphology of bentonite particulate demonstrates that hydration of GCL layers of distilled water and NaCl solution changes the particle arrangement, even though bentonite particles show more attachment to each other upon distilled water hydration.

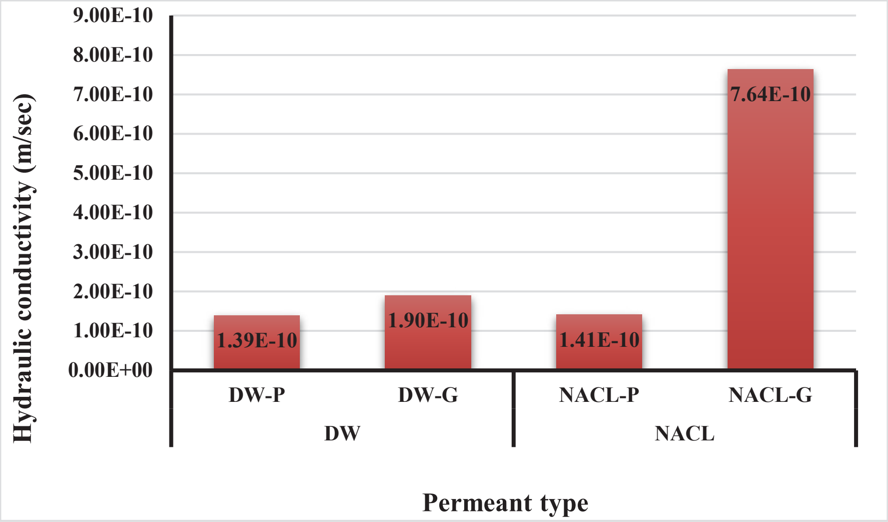

Fig. 4: Hydraulic conductivity of the GCL samples after hydration.

- The samples were hydrated with highly concentrated NaCl (50%) showing some small amounts of swelling in particles, while NaO particles were presented unevenly on the bentonite surface.
- The XRD humps show that the main elements of granular and powdered bentonite are silicon, aluminum, iron, and calcium. When GCL compounds containing granular bentonite or bentonite powder have been hydrated with NaCl solution, the flow rate of the GCL layer is enhanced because the salt impact amplifies the disintegration of calcite, leading to the loss of calcium cement and a softening of the structure of the bentonite samples. However, the bentonite powder particles effectively reduced the hydraulic conductivity rather than the granular particles.

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