APPLICATIONS OF HIGH DENSITY POLYETHYLENE IN GEOMEMBRANES

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Abstract: *A geo-membrane is a very low permeable synthetic membrane barrier used with geotechnical engineering related material. A wide variety of geo-membranes including coated woven geo-membranes that are being manufactured in the market. HDPE is one of the most comprehensively and commonly used geo-membranes in the world. These geo-membranes offer various benefits like environmental sustainability, high level of performance, reliability and durability. Those properties that have made the HDPE geo-membranes to be water resistant, covered landfills and various containment uses are discussed. One of the categories of geo-membranes is the pond liners which is made using HDPE polymer and are used for holding liquids like for lining of pools, artificial lakes etc. The geo-membrane liners are extremely useful for controlling unsafe liquids that can pollute the environment if not enclosed correctly. HDPE is certainly an excellent product for large application that requires UV and ozone resistance, chemical resistance or high quality installations. This paper particularly reviews the mentioned applications and properties to be considered.*

Keywords: *geomembrane, HDPE, sustainability, durability*

1. Introduction

As defined in ASTM D4439-00, a geo-membrane is ‘‘an essentially impermeable membrane used with foundation, soil, rock earth or any other geotechnical engineering-related material as an integral part of a man-made project, structure or system’’[1]. In general, HPDE geo-membranes consist of 96–97.5% of polyethylene resin, 2–3% of carbon black and 0.5–1.0% of other additives such as antioxidants and stabilizers [2].The relatively high crystallinity (40 to 50%) of the material provides high chemical resistance which is required in most containment facilities. However, along with this high crystallinity is an increase in the tendency for the polymer to stress crack [3]. As an important branch of geo synthetics, HDPE (high-density polyethylene) geo membranes are used as barriers against liquid and gas flow in many geotechnical applications like for instance water reservoirs, water, oil and gas storage tanks, sealing of tunnel linings, liners and covers for landfills [4, 5, 6]. Further to the function of geo membranes as cutoffs against liquid and gas flow, in many applications the mechanical interface behavior between geo membrane and soil is also an important issue, in particular when relative motions along the interface lead to a possible instability of the whole system [7, 8, 9,. Due to the viscoelastic nature of high-density polyethylene (HDPE), the strength and stiffness at lower strain rates is lower than that obtained at higher strain rates. It is therefore important to quantify the strain-rate dependence of the geomembrane stress–strain curve [10,11,12]. The objective here is to emphasis on the properties of geomembranes.

2. Microstructure of polyethylene

Semi-crystalline polyethylene materials are comprised of crystal lamellae and amorphous zones 13,14,15,16,17,]. Ref. [18] proposed a chain-folding model in which the polymer chains are neatly folded and tightly packed forming lamella. The adjacent lamellae are connected by tie molecules [19,20]. Ref. [21] extended the model by proposing that the inter-crystalline material in the amorphous zone may be comprised of [fig-1] (a) cilia that are a polymer chain with one end in the crystal lamella and other end in the amorphous zone, (b) loose loops that are chains beginning and ending in the same lamella with its mid-section in the amorphous zone, and (c) tie-molecules that connect two adjacent lamellae.

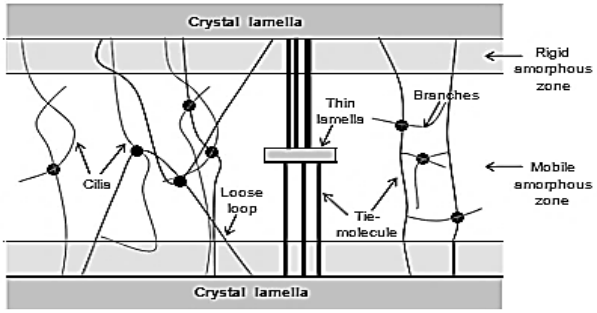

Fig 1- schematic diagram for amorphous zone showing the inter-crystalline material and the possible location of entanglements

3. Chemical properties of HDPE

HDPE contains nonpolar, saturated and high molecular weight hydrocarbons. Therefore, it has same chemical behaviour as that of paraffin. Higher crystallinity results in increase in density, mechanical and chemical stability. Most HDPE grades have excellent chemical resistance i.e. they are not attacked by strong acids or strong bases and are resistant to gentle oxidants and reducing agents. Polyethylene (other than cross-linked polyethylene) commonly can be dissolved at higher temperatures in aromatic hydrocarbons such as toluene or xylene or in chlorinated solvents such as trichloroethane or trichlorobenzene. Polyethylene does not absorbs water. The gas and water vapour permeability (only polar gases) is inferior to for most plastics. Oxygen and carbon dioxide on the other hand can pass it easily. PE can become brittle when exposed to sunlight, carbon black is usually used as a UV stabilizer. [22]

4. Application of HDPE membranes as containment barriers

Geomembranes in conjunction with compacted or geosynthetic clay liners have been widely used as barriers against the transport and migration of contaminant in waste storage and disposal landfills. Many industrial wastes, such as organic solvents, are currently dumped into landfills, especially for developing countries. Even though, polymeric geomembranes are non-porous materials and are impermeable to liquids, the waste chemicals or landfill leachate may still permeate through geomembranes by diffusion [23-27].Transport in GMs thus occurs at the molecular level [28]. However, gases and liquids can migrate through the intact GMs by an activated diffusion process that differs from the liquid convection process that occurs in the pores of porous soils [29]. Different driving forces may cause diffusion; for example, concentration, hydraulic, or temperature gradients. Diffusion has also been shown to occur even if there is no gradient: this phenomenon is called self-diffusion [30].

5. Properties to be considered

The essential properties required for HDPE geomembranes to be used as containment barriers are permeability, stress crack resistance, chemical resistance and durability. [31,32,33,34,]Organic solvents which are commonly found in landfills and hazardous waste ponds chlorinated hydrocarbons (dichloromethane, 1,2-dichloroethane, chloro-form, trichloroethylene) and aromatic hydrocarbons (benzene, toluene, styrene, ethyl benzene. [35]. Various factors that affects the oxidative degradation are geomembrane properties, exposure conditions, exposure medium and external mechanical stresses. [36,37]

6. Estimation of geomembranes service life

Often, the service life is predicted based on laboratory-accelerated tests using a time–temperature prediction models [38] .Lord and Halse [39] reviewed the work carried out by the plastic pipe industry on

the service life of HDPE pipes used in natural gas pipeline applications. These studies used elevated temperatures and stresses to determine the ductile/brittle transition point of HDPE pipe, and predicted a service life of >50 years for pipes under relatively high stresses (>7000kPa). For a geomembrane at the base of a landfill, the stresses will be much less and it is expected that accelerated aging tests at these lower stresses would indicate a longer service life (likely in the order of several hundred years).

7. Future scope

In addition to the economical aspect of the motivation for the development, more attention should be paid on the environmental issues surrounding us in these days To achieve further improvements in thermal, mechanical, and chemical properties of geomembranes, the changes in the micro-structure of the HDPE in various environmental conditions must be understand clearly. Geomembranes made by the co-extrusion of HDPE and VLDPE have several advantages over geomembranes made from either HDPE or VLDPE alone for many applications. It may have better tensile strength, tear resistance, seam strength, chemical resistance, permeability and UV resistance than VLDPE and better puncture resistance, elongation and stress crack resistance than HDPE. Coextruded, multilayer geo- membranes make available more options for the design engineer attempting to find the best product for a given application.

8. Conclusion

The uses of HDPE geomembranes in various applications along with its properties are discussed. HDPE geomembranes are widely used geomembranes worldwide due to its good chemical resistance and it acts as better barriers system for many solvents that can affect the durability of HDPE geomembranes.

9. References

1. ASTM D4439-00. Standard Terminology for Geosynthetics. Vol. 04.09.
2. Apse, J.L., 1989. Polyethylene resins for geomembrane applications. In: Koerner, R.M. (Ed.), Durability and Aging of Geosynthetics, Elsevier Applied Science Publisher,Amsterdam, Netherlands, pp. 159–176
3. Y. Grace Hsuan, Drexel University, 475 Kedron Ave., Folsom, PA 19033, USA, Geotextiles and Geomembranes 18 (2000) 1-22
4. Müller,W.W.,2010. HDPEGeomembranes in Geotechnics Springer Berlin Heidelberg, Germany ISBN 978-3-642-072 10-9.
5. Koerner,R.M.,2012.sixthed.Designing with Geosynthetics, vol.1 Xlibris Corporation, Bloomington, IN, USA.
6. Pavanello,P.,Carrubba,P.,Moraci,N.,2018.Dynamic friction and the seismic performance of geosynthetic interfaces, Geotext.Geomembranes46(6),715–725.
7. Stamatopoulos, A.C., Kotzias,P.C.,1996. Earth slide on geomembrane. ASCEJ. Geotech. Eng. 122, 408–411.
8. Palmeira, E.M., 2009. Soil- geosynthetic interaction: modeling and analysis. Geotext. Geomembranes 27(5), 368–390
9. Saravanan, M., Kamon, M., Ali, F.H., Katsumi, T., Akai, T., 2008. Landfill interface study online member selection for stability. Electron.J.Geotech. Eng.13,1–14.
10. Henri P. Sangam, R. Kerry Rowe, GeoEngineering at Queen's-RMC, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada K7L 3N6, Geotextiles and Geomembranes 19 (2001) 329–35
11. Zhang, C., Moore, I.D., 1997a. Nonlinear mechanical response of High Density Polyethylene. Part I: experimental investigation and model evaluation. Polymer Engineering and Science 37 (2), 404–413.
12. Beijer, J.G.J., Spoormaker, J.L., 2000. Modelling of creep behaviour in injection-moulded HDPE. Polymer 41, 5443–5449.
13. Nikolov, S., Doghri, I., 2000. A micro/macro constitutive model for the small-deformation behaviour of polyethylene. Polymer 41, 1883–1891.

14. Amano T, Kajita S, Katayama K. Comments on the morphology of polymers crystallized from oriented melts. Prog Colloid Polym Sci 1975;58:108-13.
15. Bassett DC. Polymer spherulites: a modern assessment. J Macromol Sci Part B: Phys 2003;42(2):p 27-56.
16. Hoffman JD, Lauritzen Jr JI. Crystallization of bulk polymers with chain folding: theory of growth of lamellar spherulites. J Res Nat Bur Stand-A Phys Chem 1961;65A:297-336.
17. Keith HD, Padden FJ. The optical behavior of spherulites in crystalline polymers.1. Calculation of theoretical extinction patterns in spherulites with twisting crystalline orientation. J Polym Sci 1959;39(135):p 01-22.
18. Lustiger A, Markham RL. Importance of tie molecules in preventing poly- ethylene fracture under long-term loading conditions. Polymer 1983;24(12):16 47-54.
19. Keller A, Machin MJ. Oriented crystallization in polymers. J Macromol Sci Part B Phys 1967;1(1):41-91.
20. Keller A. A note on single crystals in polymers e evidence for a folded chain configuration. Philos Mag 1957;2(21):1p 1-5.
21. Keith HD, Paden Jr FJ, Vadimsky RG. Further studies of intercrystalline links in polyethylene. J Appl Phys 1966;37(11):40 27-34.
22. https://en.wikipedia.org/wiki/Polyethylene#cite_note-Ullmann-14
23. A.J. Keller, M.J. Machin, J. Macromol. Sci. Phys. B1, 41 (1967)
24. T.B. Edil, Waste Manage. 23 (2003) 561–571.
25. H.P. Sangam, R.K. Rowe, Geotext. Geomembr. 190 (2001) 329–357.
26. T.M. Aminabhavi, H.G. Naik, J. Hazard. Mater. B 64 (1999) 251–262.
27. J.K. Park, J.P. Sakti, J.A. Hoopes, ASCE J. Environ. Eng. 122 (1996) 807–813.
28. Lambert, S., Touze-Foltz, N., 2000. A test for measuring permeability of geo- membranes. In: Proceedings Eurogeo 2, Bologna, Italy, p. 10.
29. Barroso, M.C.P., Lopes, M.D.G.A., Bergamini, G., 2010. Effect of the waste pressure on fluid migration through geomembrane defects. In: Proceedings 9 ICG, Guaruja, Brazil, pp. 959-962.
30. Eloy-Giorni, C., 1993. Etude des transferts diffusifs dans les geomembranes : mécanismes et mesures à l'aide de traceurs radioactifs. Thèse de l'université J. Fourier, Grenoble 1, CEA, p. 174 (in French).
31. Keh-Ping Chao, Ping Wang, Ya-Ting Wang, Diffusion and solubility coefficients determined by permeation and immersion experiments for organic solvents in HDPE geomembrane, Journal of Hazardous Materials 142 (2007) 227–235.
32. Peggs ID, Carlson DS. Stress cracking of polyethylene geomembranes. In: Koerner RM, editor. Field experience, durability and aging of geosynthetics. London: Elsevier Applied Science; 1989. pp. 195-271.
33. Halse YH, Lord Jr AE, Koerner RM. Ductile-to brittle transition time in polyethylene geomembrane sheet. In: Koerner RM, editor. Geosynthetic testing for waste containment applications, ASTM STP 1081. Philadelphia: ASTM; 1990. pp. 95-109.
34. Giroud JP. Determination of geomembrane shattering cracks. Geosynth Int 1994;1(2):149-80.
35. Viebke J, Elble E, Ifwarson M, Gedde UW. Degradation of unstabilized medium-density polyethylene pipes in hot-water applications. Polym Eng Sci 1994;34(17):13 54-61.
36. Kelen, T., 1983. Polymer Degradation. Van Nostrand Reinhold, New York, NY, 211p.
37. Osawa, Z., 1992. Photo-induced degradation of polymers. In: Hamid, A.H., Amin, M.B., Maadhah, A.G. (Eds.), Handbook of Polymer Degradation. Marcel Dekker, New York, USA, pp. 169–217
38. Müller W, Jacob I. Oxidative resistance of high density polyethylene geo- membranes. Polym Degrad Stab 2003;79(1):161-72.
39. Lord, A.E., Halse, Y.H., 1989. Polymer durability the materials aspect. In: Koerner, R.M. (Ed.), Durability and Aging of Geosynthetics. Elsevier, Amsterdam, Netherlands, pp. 293–329.