Overview of Polyethylene Based Multi-layered Geomembrane Through Blown Extrusion Process

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Abstract. Geomembranes are low-permeable liners used to control the molecular migration in many proven applications. Landfills is most common application in the field of civil and environmental engineering. Geomembrane is the main component in lining system which works as hydraulic barrier. The polyolefins are the basic materials of liner and more commonly polypropylene and polyethylene are preferred. Commercial manufacturing process involves extrusion techniques viz cast extrusion and blown extrusion process. The individual process is designed for multiple layered structures which are then coextruded to lead into a single liner. Typical structure comprises, high to low-density polyethylene (PE) resin, processing aids, stabilisers to retard the degradation through ultra-violet rays, photo-oxidation, and thermal oxidation. The stabilizer is usually used in smaller dosses to avoid degradations which includes, 2 to 3% carbon-black (CB), 0.5 to 1% antioxidants (AO), and plasticizing additives to introduce the flexibility. During the process, components are homogenised in specially designed screws of feeding and mixing zones. The formulated melt is co-extruded through specially designed die of multi-layered structures. The subsequent melt enters in circular die with a certain pressure which leads to bubbled shaped films. The variation in the surface morphology layer structure and layer number are the important technical aspects to alter the required end application. Finally, manufactured geomembrane is qualified as per the international specifications which are governed by geosynthetic research institute (GSI/GRI).

Key words: Geomembrane, Polyethylene, Blown, Extrusion, Landfills, Barrier

1. Introduction

Geosynthetic lining includes in landfills projects as lining system in the base liner form and capping system. Landfills are imperative structure in modern society those designed to permit maximum wastes accumulation in minimum space to prevent environmental contamination [1,2]. Polyolefins

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are main constituent for liner and are made from various geosynthetics including geomembranes, geonets, geotextiles, geosynthetics clay liners. The geomembranes are commonly used in geotechnical and environmental related developments. Geomembranes is indispensable material component in liner systems which mainly contributes a hydraulic barrier [1-3]. According to ASTM D4439-00, a geomembrane is an essential barrier membrane used with foundation, rock earth, soil, or any other geotechnical engineering-related material as an integral part of artificial structure or system [3]. Due to their common use in most environmentally related applications, polyethylene (PE) based geomembranes were focused throughout the study. Municipal Solid Waste (MSW) accumulated in landfills usually treating with various methods such as, sanitary landfilling, dumping, incineration and compost. The burials of MSW in landfills will persist for many decades. The longer accumulation and storage process cause anaerobic decomposition of organic waste and landfill gas emission. The landfills gas majorly comprises anthropogenic methane and carbon dioxide emissions. The minor components contain over a hundred of undesirable potentially toxic chemical compounds [1,4].

HDPE receiving more attention in geosynthetics industry due to its balanced mechanical properties, reasonable cost, and low processing energy. Because of wider application in geosynthetic industry, there is an increasing need to address their performance and evaluate their service life. The atmospheric condition especially high energy radiation of UV-A and UV-B are to break the covalent-bonds in HDPE chains which generate free radicals. This free radical mechanism propagates to series of radical reactions with time leads exponential degradation in polymer [1,2].

The landfills covering system encompass partial or complete isolation of waste from the surrounding environment. Geosynthetic materials such as geosynthetic clay liners, geomembranes, compacted soil liners, compacted clay liners, and HDPE geomembranes have been widely employed at the bottom of landfill. The advantages of these materials are mainly consistent physical properties, low leakage rates, and longer-service life, and reusability. The other advantage of HDPE geomembrane layer is that it can be used repeatedly as a low hydraulic barrier and does not occupy the space of landfills. Furthermore, using HDPE geomembrane is cost effective. It would be much more cost saving if the HDPE geomembrane layer is reused. The recent study on using HDPE geomembranes as a substitute for intermediate cover in landfills improved the gas extraction ability. Chen at el., demonstrated that after welding HDPE geomembranes leads whole air tight layer on larger area of landfill, the gas flow in the general pipe increased 25% comparing with the design that the HDPE geomembranes were not welded together [1]. Traditional geomembranes are versatile in application and adaptable to many different field conditions. This can be combined with many building materials which are utilized in range of applications such as civil engineering, water resources, environment, coastal, mining engineering, erosion control engineering, etc. The added benefits for geomembranes come from their fundamental characteristics such as non-corrosiveness, resistant to chemical, biological disintegration, high flexibility, lightness due to lower density, simplicity in installation which speeds up the construction works and good aesthetic look as well. Eco-friendly geomembranes are known for offering economical, technically efficient solutions for civil engineering construction practices.

This article provides brief overview of HDPE geomembrane utilization including different categories and properties. The evaluation based on standard specifications for required application are also explained. The blown extrusion process is accommodated to manufacture multi-layered films/sheets produced in roll form. The liner is upto 8-meter lay-flat width and thickness ranges from 0.5 mm to 3.0 mm. The design and working mechanism of additives defines the in-service life of a geomembrane during its application. To manufacture more speciality products, “Megaplast India Pvt Ltd (Megaplast)” is now expanding its product portfolio with high graded geomembranes for barrier applications. The speciality of barrier geomembranes is to provides very-lower permeation of various gases such as methane, oxygen, water vapour, and volatile organic compounds (VOC’s) includes, x-xylene, toluene, benzenes, etc.

2. Standard product features and specifications

Megaplast has a globally certified laboratory to assure the quality of products manufactured for our customers. The testing protocols strictly following the respective standards based on international certifications defined by ASTM. Geomembrane is tested as per the GRI-GM13 and GRI-GR17 standards for HDPE and LDPE respectively [5, 6]. The involved major test parameters are highlighted as below points:

2.1 Base Resin: Geomembranes are made from virgin polymers of HDPE and/or LDPE not containing reprocessed polymer with required thickness of 0.5 to 3.0 mm and customised colour.

2.2 Oxidative Induction Time (OIT): OIT is measured in two configurations: standard-OIT and HP-OIT tests are performed with

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differential scanning calorimeter in air and nitrogen atmosphere. The pressure is used while conducting the HP-OIT test.

2.3 Carbon Black Content (CBC): The test is performed according to ASTM D 1603, with a specified range from 2 to 3 % and above 3% there is no significant improvement for ultraviolet resistance.

2.4 Carbon Black Dispersion (CBD): The significance of this property is to conform proper dispersion based on observation from ten microtome slides. The slides are taken from various locations along the width direction geomembrane. The image observed under 100x of a transmission light microscope is compared with patterns from reference chart. Nine of ten views should be in Category 1 or 2 and one can be of Category 3.

2.5 Ultraviolet (UV) Resistance: The material's UV resistance is a critical property and only the HP-OIT is recommended to confirm the UV resistance test. The average HP-OIT retained value is initially set at 50%.

2.6 Oven Aging: The OIT is designed as an index test to verify the existence of antioxidants after high temperature exposure. The retention percentage cannot be less than 55% for std-OIT or 80% for HP-OIT testing.

2.7 Stress Cracking Resistance (SCR): This property is evaluated using the Notched Constant Tensile Load test (NCTL) as 500 hours failure time as per ASTM D 5397.

2.8 Mechanical Testing Methods: Universal testing machine (UTM) is used to access the elongation, puncture test, tensile yield, tensile break tests and modulus properties.

3. Background mechanism and technical understanding of the blown extrusion process

The conventional geomembranes are manufactured using petrochemical based polyolefin materials of various types and grades. The commercial use of PE liner for storage purpose for solid and/or liquid is widespread due to the low cost, and durability as compared to other materials. The process of blown extrusion is shown in Fig. 1 (a) and crystallization mechanism in Fig. 3(b). PE liner is manufactured by an extrusion method and process uses a specifically designed die of horizontal or circular die lip. Megaplast blown film extrusion process uses circular die which forces the molten formulation of polymer between two concentric die lips which are oriented vertically upward direction. The resulted smooth polymer sheet of closely controlled thickness from 0.5 to 3.0 mm and 8-meter as lay-flat width. Textured surface is obtained by creating surface roughness on smooth sheet texturing. Nitrogen gas is employed during co-extrusion process for surface texturing. The textured geomembrane having single or double side textured. Textured surface is intended to increase the interface shear strength when compared with the interface strength for smooth geomembrane. Daniel et al., have studied that geomembrane surface asperity influences the shear strength and shear mechanism occurring at the interface [7].

Formulated melt starts the crystallization process (solidification) when the temperature decreases below its melting temperature. The crystallisation starts from nuclei and growing radially outward direction in rod-like fibrils which creates spherulite structure as shown in Fig. 3(b). The macromolecular chains are neatly folded and tightly packed in crystal lamellae which are separated by amorphous region of randomly fold. In the individual lamellae macromolecular chains are structurally arranged in regular folding manner and it depends on the cooling condition and property of processing materials [7,8].

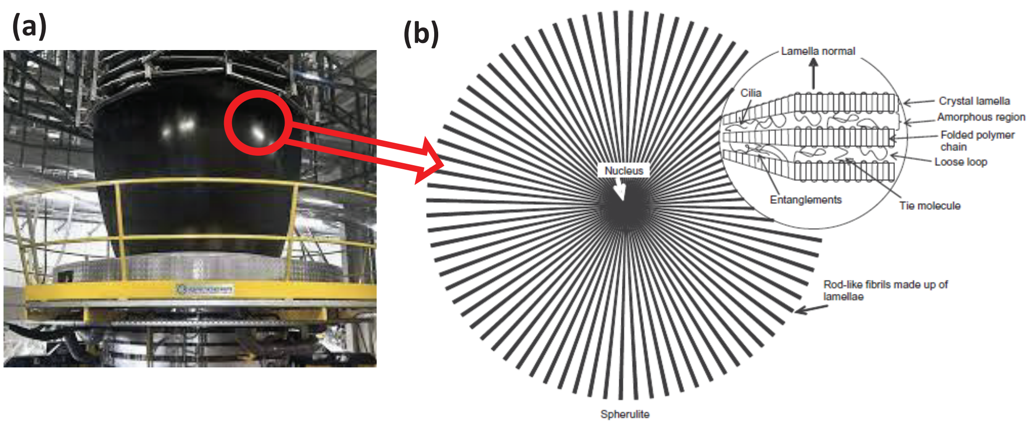

Figure 1: (a) Blown extrusion process, and (b) crystallisation(solidification) mechanism (copied from reference) (Copyright permission will apply if required)

4. Product categories:

Megaplast manufactures three types of geomembrane films for both HDPE and LDPE. The product portfolio is summarised in Fig. 2. based on surface morphology, (a) both side textured, (b) both side smooth, and (c) one side textured and one side smooth. The further customisation in terms of colour, thickness, barrier property and induced flexibility are also possible.

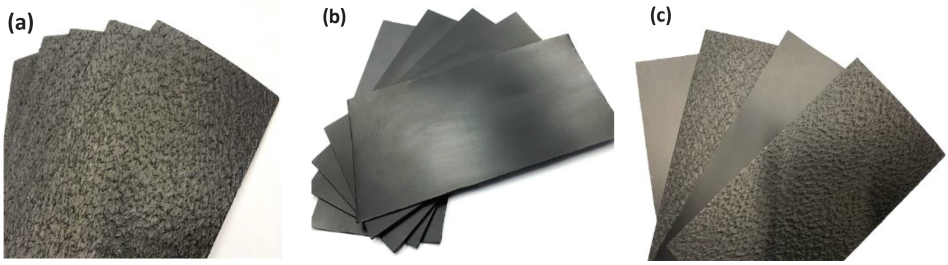

Figure 2: Variation in geomembranes, based on material types and surface morphology: a) double side textured, (b) double side smooth, and (c) one side textured and one side smooth

5. Life prediction of geomembrane

In modern society geomembrane plays an important role in geosynthetic engineering. These are used as part of barrier systems for the containment of generated fluids from various man-made projects such as water treatment, heap-leach mining, and landfills (municipal solid waste, industrial waste), etc. The longer contaminating lifespan of these projects like landfills can be centuries long. Geomembrane manufacturers are expected that any geomembrane used in barrier system be able to perform its intended function which employed good construction and installation practices. The time span that geomembrane perform its barrier function for designed containment to environment is called its service life. Geomembrane will experience both physical ageing and chemical ageing during its service [1]. In physical ageing, macromolecular chains of the geomembrane experienced stable equilibrium state and does not involve breakage of covalent bonds. In other hand, chemical ageing process involves breakage in the polymer chain in terms of carbon-carbon bonds which lead free radicals in system. Thus, the atmospheric conditions include oxygen and temperature as majorly influencing parameters for the chemical ageing to induce the chain breaking through oxidation and thermal degradations [1,2]. The reactive free radicals forms and start propagating the chain breaking and cross-linking mechanisms. The process causes the random polymeric chain-scissoring which alters its molecular weight and molecular weight distributions (polymer dispersive index). The fragmented polymer chains are formed within geomembrane through spontaneous catalytic reactions. The exponential reducing in molecular weight with time span is directly proportional to chain-scissoring mechanism which leads very slowly deterioration in mechanical properties and eventually failure. To overcome the deterioration and /or degradation of PE materials many additives such as antioxidants and stabilizers are mixed during extrusion process. The stage of antioxidant depletion is the initial and most important stage of the PE geomembrane aging process. In general, to inhibit the PE geomembrane chain-scissoring process through photo-oxidation, 2 to 3 percentage of carbon black is preferably used. Thermal degradation is controlled through the proper combinations of primary and secondary antioxidants through the concentrated antioxidant masterbatches. Koerner et al., categorized the antioxidant depletion process into three conceptualized stages and those are schematically represented in Fig. 3 [8].

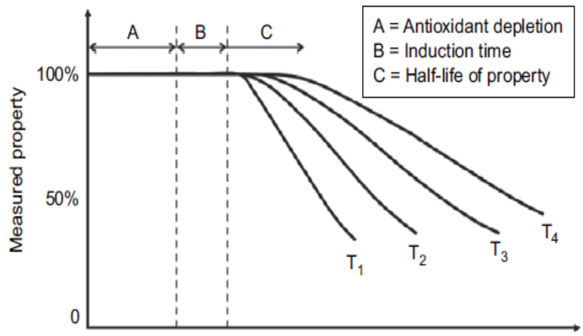

Figure 3: Graphical representation of three stages of antioxidant depletion. Its copies from Ref. 1 (Copy write permission will apply if necessary)

i. Stage I (Antioxidant depletion)- The antioxidant depletion can be assessed using OIT. The OIT is defined as a relative measure of a materials resistance to oxidative decomposition by the measurement of the time interval to onset of exothermic oxidation at specified temperature and oxygen atmosphere. This is accessed in two configurations of Std-OIT and HP-OIT using DSC.
ii. Stage II (Induction time) – The oxidation of the geomembrane resin begins at this stage. Oxidation occurs exponentially and degree of degradation is often immeasurable.
iii. Stage III (Half-life of Property) – The degradation in this stage is often preceded by a rapid rate which leading to significant change in mechanical properties. Thus, end of this period characterized by half-life of property.

The earlier study for the prediction of HDPE is summarised based on in-service temperature and these oxidation stages is 445 years in 20-degree Celsius temperature [9].

Geomembranes manufactured from HDPE have a relatively higher crystallinity. Therefore, the evaluation of stress crack resistance (SCR) is the concern. SCR of HDPE geomembranes can evaluate by both the bent strip and NCTL tests. Hsuan at al has investigated bent strip and NCTL test for 16

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sample and conclude that the bent strip test could not adequately predict the stress cracking field performance whereas the NCTL test could distinguish the SCR of geomembrane [9-11].

6. Technical discussion on barrier geomembrane

Traditional geomembranes based on LDPE and HDPE polymers provide excellent hydraulic barrier along with mechanical properties and good chemical resistance in landfills leachates. The leachate contains wide range of aromatic hydrocarbons and halogenated volatile organic compounds (VOC's). The aromatic hydrocarbon includes benzene, toluene, ethyl-benzene, xylene all are collectively called BTEX. To overcome this issue and prevent our mother earth and living organism in globe a geomembrane engineering is most important element in modern landfills. The incorporating a thin layer of ethylene vinyl alcohol (EVOH) into traditional geomembrane through coextrusion can improve the barrier for VOC's. The EVOH is a copolymer of ethylene and vinyl alcohol, being advantageous to its low permeability layer to BTEX and other gases. The classification of EVOH is based on the molecule percentage of ethylene (i.e., 32 mol % EVOH contains 32% ethylene and 68% vinyl alcohol) content. The outline of final layer structure with EVOH and tie layer will be PE/Tie/EVOH/Tie/PE and it varies as per the end property alteration and processing point [10]. Fig. 4 represents schematically the structure of HDPE with EVOH in single layer as sandwiched structure. The researchers have developed engineered structure of multi-layered geomembrane to achieve the proper barrier. Thus, co-extruding an outer PE layer with sandwiching the thin layer of EVOH in core layer which combines the advantageous properties for both water and hydrocarbons. The outer polyethylene layers minimize moisture migration to the hydrophilic EVOH layer. Subsequent EVOH layer provides the primary resistance to the diffusion of hydrocarbons, this modification in multilayer structural engineering introduces the barrier property for moisture and hydrocarbons.

Figure 4: Schematical representation of HDPE/EVOH structure for barrier geomembrane

7. Conclusions:

This study has explored scopes for conventional geomembrane applications and testing standards. Geomembrane durability is a major issue for all types for long designed lifetime. Proper selection of additive packages and doses are important to inhibit the degradation exponentially. Theoretical explanation through reference pattern of the antioxidant depletion period of HDPE geomembranes supports to understand the degradation mechanism during its service life. This supports to understand the working mechanism of antioxidant during its in-service life and it really depends on surrounding conditions for antioxidant depletion. The technical discussion on understanding crystallization process and antioxidant role for in-service life prediction has covered. Moreover, the speciality geomembrane for gas barrier and structural engineering of HDPE with EVOH for multiple gases. The technical understanding the role of sandwiched EVOH layer is advantageous to understand the structural integrity. This study gives strong outline information to end users (customer) to select the proper geomembrane for end application. This proves the gas extractions wells, containment of greenhouse gases getting advantages that EVOH sand-witched geomembranes offer for intermediate and clear solutions.

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