Microstructural Investigation of UV-Degraded Geotextiles/Geomembranes through Scanned Electron Microscopic Study

Dr. Vivek G. Bhartu

764-E, Umrigar Building, Parsee Colony, Dadar, Mumbai 400014, India

Abstract: It is well established that geotextiles/geomembranes polymers undergo degradation of their mechanical properties, electrical properties, rheological properties when exposed to UV-radiation. The degradation of strength depends upon the physical properties viz. thickness vis-à-vis mass per unit area, exposure period and the condition under which the geotextiles/geomembranes polymers are exposed. The polymers: PET/PP/PVC/HDPE widely used as geotextiles/geomembranes were exposed to artificial UV-radiation with the accelerated rate under various exposure conditions and the degradation of their mechanical properties has been evaluated. The results for degradation of strength are presented elsewhere. The visual inspection of the process of degradation of UV degraded polymers is studied through SEM micrographs and the results are presented here.

Key words: Geotextile, geomembrane, SEM, UV-degradation.

1. Introduction

The polymers like PET and PP used as geotextiles and PVC and PE used as geomembranes lose their tensile strength when exposed to UV-radiation. The degradation of strength is a function of exposure period and mass per unit area of polymeric material. It has been established that the degradation of strength further depends upon the condition under which material is exposed to UV-radiation.

Geotextiles and geomembranes are widely used in engineering applications and the synergistic effects have impact on degradation of strength to large extent. During the field application, the material comes in contact with soil, water or combination of soil and water. The chemicals, metals, salts present in soil have additional effect on degradation of strength as compared to freely exposed material to UV-radiation.

The microstructural investigations are carried out on UV-degraded geotextiles/geomembranes with the help of micrographs through SEM (scanned electrons

microscopes). The process and reasons of UV-degradation have been studied and explained with the help of SEM micrographs.

2. Literature Review

The earlier researchers have quantified the degradation of strength due to UV-radiation but the explanation for the process and detailed visual inspection of geotextiles fibers have not been reported and this is a necessary study in this direction.

Mukharjee and Arwika [1] explained the degradation process of E-glass fibers with the help of SEM micrographs and suggested that microvoids in the form of white spots develop on polymers which indicate the degradation of strength.

3. Experimental Set up and Testing Procedure

Accelerated ageing condition of UV-radiation has been simulated in the laboratory for Mumbai weathering conditions.

The average incidental solar radiation in Mumbai is

Corresponding author: Vivek G. Bhartu, Dr., consulting engineer, research field: geo-technical engineering.

5,000 w.h./m²/day obtained from meteorological data. The bright sunshine hours in Mumbai are 8 h and the rate of accelerated ageing has been selected as 1 h of exposure under artificial UV-lamp of UV-intensity 127 w/m² equivalent to 0.375 day of solar radiation.

Test specimens of PET and PP (Nonwoven) and PVC and HDPE are chosen and exposed under artificial UV-radiation for 450 h under various exposure conditions, viz. freely exposed, submerged in water, in contact with soil and in contact with soil and in contact with soil and water.

As the polymers used for testing are non conductive material, the test specimens were gold-coated.

The unexposed and conditioned exposed test specimens were placed under SEM and the images were obtained.

When the test sample is placed under UV radiation, one surface is exposed to UV radiation and other surface remains unexposed. The cross sectional view of UV-degraded PET and PP at exposed and unexposed surface (edges) was magnified 200 times and compared with the respective cross sectional view of unexposed sample.

Similarly, the cross sectional view of UV-degraded PVC and HDPE was magnified 3,500 times and compared with unexposed sample.

4. Results of SEM Study

The SEM micrographs through cross section of PET and PP exposed under artificial UV-radiation for various exposure conditions are presented in Figs. 1-17.

The SEM micrographs through cross section of PVC and HDPE test specimens exposed under artificial UV-radiation for various exposure conditions are presented in Figs. 18-27.

5. Discussion on SEM Study of Geotextiles/Geomembranes

Fig.1 shows the cross sectional view of unexposed PET (Nonwoven) test specimen having 2.10 mm

thickness. The cross sectional view is magnified 200 times at the edges of both the surface which is shown in Figs. 2 and 3. The same specimen is freely exposed under artificial UV-radiation for 450 h and the magnified cross section near exposed surface AB is shown in Fig. 4 and near unexposed surface is shown in Fig. 5.

It has been observed from Figs. 2 and 3 that the fibers of PET near surface are dense and intact. Most of the fibers are having uniform diameter and cylindrical shape.

Fig. 1 Cross-sectional view by SEM of unexposed polyester (Nonwoven).

AB = Exposed surface to UV-radiation; CD = Unexposed surface to UV-radiation.

Fig. 2 Micrograph of unexposed PET (Nonwoven) near surface AB.

While comparing the micrographs of Fig. 2 with Fig. 4 and Fig. 3 with Fig. 5, it is seen that the fibers of freely exposed PET and PP near exposed surface found disintegrated. The fibers near unexposed surface become dense compared to its original network. This indicates that the surface tension is developed on the surface exposed to UV-radiation. The disintegration of fibers is the main cause for degradation of tensile strength of geotextiles freely exposed to UV-radiation.

While comparing the micrographs of Fig. 2 with Fig. 6 and Fig. 3 with Fig. 7, it has been observed that the fibers of PET and PP exposed to UV-radiation when submerged in water are found less disintegrated near exposed surface compared to freely exposed condition. The fibers near unexposed surface become dense, which shows that the surface tension is reduced under this condition due to less penetration of UV-photons in the water. Hence, the degradation of tensile strength is less when the geotextiles are submerged in water and exposed to UV-radiation.

While comparing the micrographs of Fig. 2 with Fig. 8 and Fig. 3 with Fig. 9, it has been observed that similar trends of disintegration of fibers are found for PET/PP in contact with soil and soil/water and exposed to UV-radiation. However, the fibers near exposed surface and unexposed surface are found ruptured. The fibers near unexposed surface are more ruptured due to continuous contact with soil which contains metals, chemicals and pollutants. The colour of fibers has become dark near exposed surface due to entrainment of soil particles in the voids of the fabric from saturated soil.

While comparing the micrographs of Fig. 2 with Fig. 10 and Fig. 3 with Fig. 11, it has been observed that the fibers of PET/PP are found severely damaged near both the surfaces when the test specimens are in contact with soil and water and exposed to UV-radiation. At some points, the shape of originally cylindrical type of fiber has been changed completely. This may be due to the metals, chemicals and salts present in soil. Hence, the degradation of strength is maximum under this condition compared to other conditions.

Fig. 3 Micrograph of unexposed PET (Nonwoven) near surface CD.

Fig. 4 Micrograph of PET (NW) freely exposed to UV-radiation (near exposed surface).

Fig. 5 Micrograph of PET (NW) freely exposed to UV-radiation (near unexposed surface).

Fig. 6 Micrograph of PET (NW) submerged in water and exposed to UV-radiation (near exposed surface).

Fig. 9 Micrograph of PET (NW) in contact with soil and exposed to UV-radiation (near unexposed surface).

Fig. 7 Micrograph of PET (NW) submerged in water and exposed to UV-radiation (near unexposed surface).

Fig. 10 Micrograph of PET (NW) in contact with soil + water and exposed to UV-radiation (near exposed surface).

Fig. 8 Micrograph of PET (NW) in contact with soil and exposed to UV-radiation (near exposed surface).

Fig. 11 Micrograph of PET (NW) exposed to UV-radiation (near unexposed surface).

Fig. 12 Cross sectional view by SEM of unexposed polypropylene (Nonwoven).

AB = exposed surface; CD = unexposed surface.

Fig. 15 Micrograph of PP (NW) submerged in water and exposed to UV-radiation (near exposed surface).

Fig. 13 Micrograph of unexposed PP (NW) (near surface AB).

Fig. 16 Micrograph of PP (NW) in contact with soil and exposed to UV-radiation (near exposed surface).

Fig. 14 Micrograph of PP (NW) freely exposed to UV-radiation (near exposed surface).

Fig. 17 Micrograph of PP (NW) in contact with soil + water and exposed to UV-radiation (near exposed surface).

Fig. 18 Micrograph of unexposed PVC (UV-unstabilised).

Fig. 21 Micrograph of PVC (UV-unstabilised) in contact with soil and exposed to UV-radiation.

Fig. 19 Micrograph of PVC (UV-unstabilised) freely exposed to UV-radiation.

Fig. 22 Micrograph of PVC (UV-unstabilised) in contact with soil and water and exposed to UV-radiation.

Fig. 20 Micrograph of PVC (UV-stabilised) submerged in water and exposed to UV-radiation.

Fig. 23 Micrograph of unexposed HDPE (UV-stabilised).

Fig. 24 Micrograph of HDPE (UV-stabilized) freely exposed to UV-radiation.

Fig. 27 Micrograph of HDPE in contact with soil and water and exposed to UV-radiation.

Fig. 25 Micrograph of HDPE (UV-stabilized) submerged in water and exposed to UV-radiation.

Fig. 26 Micrograph of HDPE (UV-stabilized) in contact with soil and exposed to UV-radiation.

While comparing Fig. 18 with Figs. 19-22, it has been observed that morphology of UV exposed and unexposed specimen of PVC-1 has shown the co-continuous morphology in all cases. While, in case of cross sectional view of PVC-1 in contact with soil for 450 hours has shown some white spots, indicating the UV degradation to much larger extent as compared to other exposed samples at different conditions. This may be attributed to high reactivity of PVC-1 specimen when exposed to UV radiation in contact with soil.

In PVC test specimen, the lines of white spots through cross section are observed. These lines may be attributed as microcracks or lines of failure through cross section. The test specimen freely exposed to UV-radiation does not show any significant change in morphology of unexposed surface. The test specimen exposed when in contact with soil shows white spots through entire cross section in Fig. 21. It means that the degradation of PVC occurred through entire cross section including unexposed surface. It is also seen in Fig. 22 that the white spots are connected by long line of 1 micrometer thick through the entire cross section when the test specimen is exposed in contact with soil and water. This attributes that microcracks are developed through the entire cross section of PVC specimen under this condition.

The loss of tensile strength of PVC exposed to UV radiation when in contact with soil is 34% and the same 40% when in contact with soil and water. The length of microcracks and percentage of white spots per unit area are significant factors of loss of tensile strength which is more as compared to PVC test specimen exposed in contact with soil and water.

While comparing Figs. 23-27, it has been observed that since the chloride atom present in PVC is polar in nature and the soil and water is also polar, the chlorine reacts with soil and water when coming in contact with water and soil. Hence there is bond breakage of -Cl from PVC material which may be the cause of more degradation of PVC when exposed in contact with soil as well as soil and water as compared to freely exposed condition.

In case of HDPE, the SEM analysis has revealed the co-continuous morphology. The appearance of white spots in this case is to a lesser extent as compared to PVC for all the cases. This can be also explained with the structural difference as well as different reactivity of specimens on UV exposure.

The percentage of white spots and microcracks are less in HDPE test specimen as compared to PVC for all conditions. The loss of tensile strength of HDPE when exposed to UV lamp and in contact with soil is 24% and in contact with soil and water is 30%. The loss of tensile strength of HDPE is less as compared to PVC for all the conditions. This reveals that the degradation of geomembranes depends upon percentage of white spots and microcracks developed due to UV-radiation.

PVC is more susceptible to UV-degradation as compared to HDPE due to presence of chlorine in PVC.

6. Conclusions

All the polymeric material used geotextiles and geomembranes lose their mechanical properties when exposed to UV-radiation. The degradation of mechanical properties is a function of exposure period, thickness vis-a-vis mass per unit area of the material

and the condition under which the polymer is exposed to UV-radiation. The loss of strength is due to the intermolecular bond breakage of polymer chains which can be observed through SEM image.

SEM images through cross-section of geotextiles reveal that voids are developed within fibers which are identified by white spots up to the depth of 5 microns from exposed surface which is considered to be "damage zone". The penetration of UV-photons is less beyond the damage zone and hence the degradation of tensile strength is less for thicker/high mass per unit area material.

SEM images also reveal that the fibers in the damage zone are locally ruptured and more disintegrated when coming in contact with soil or soil and water. The local rupture of fibers is due to presence of metals, chemicals and salts in the soil and the disintegration of fibers is due to colloidal soil particles enter in the voids of fabric from saturated soil due to uplift pressure. The colloidal soil particles absorb UV-energy which creates additional thermal stress on geotextiles. Hence the loss of tensile strength is more under these conditions as compared to freely exposed condition.

SEM images through cross-section of geomembrane reveal that microvoids are developed in the resin due to breakage of intermolecular bonds. The microvoids are identified by white spots up to depth of 15 to 20 microns from the exposed surface which is considered to be "damage zone". The penetration of UV-photons is less beyond the damage zone and hence the degradation of tensile strength is less for thicker material.

SEM images also reveal that the intermolecular bond breakage in case of HDPE and weakening intermolecular interaction between PVC resin and filler is more when geomembrane comes in contact with soil and soil/water. The bond scissioning is more due to presence of metals, salts and chemicals in soil. Hence the degradation of strength of geomembrane is more when in contact with soil or soil/water and exposed to UV-radiation as compared to freely

exposed condition.

the SEM micrographs of the test samples.

Acknowledgements

The author acknowledges Sardar Patel College of Engineering (Mumbai) and Bombay Textile Research Association, Mumbai for their contribution to imaging

References

- [1] Mukharjee, A., and Arwika, S. J. 2005. "Performance of Glass Fiber-Reinforced Polymer Reinforcing Bars in Tropical Environments." *ACI Structural Journal* 102 (6): 816-22.