Long term performance of geosynthetics

Müller-Rochholz, Jochen
University of Applied Sciences, Münster, muero@fh-muenster.de
Retzlaff, Jan
Geoscope, j.retzlaff@geoscope.eu

Keywords: creep, creep rupture, damage during installation, fatigue, thermo oxidation, SIM, hydrolysis, PET, PP, PE

ABSTRACT: The long term performance is shown under the aspects of mechanical loads (creep, creep rupture), damage during installation and following sustained load, fatigue testing and chemical degradation by thermo oxidation of PP and hydrolysis of PET.

1 INTRODUCTION

Long term behavior is an essential aspect, in the application of geosynthetics in roads, bridges, landfills, coastal protection. Some characteristics are limited by external mechanical exposure, some by the internal polymeric structure, some by external chemical exposure. This paper shows the state of the art concerning creep, creep rupture, damage during installation and chemical degradation.

Landfill owners (in Germany) expect a proven service life of geosynthetics applied in the landfill exceeding 100 years. Also infrastructure elements as dams, roads, railroads, bridge abutments shall last for long time. To assure these service life values, intensive testing has to be performed and calculation methods have to be developed or executed to get reliable numbers.

2 CREEP AND CREEP RUPTURE

The stress sustained for the whole service life of a geosynthetic is determined by creep rupture extrapolation of tests like those shown in figure 1, 2 at single rib/strand tests, also on wide width specimen.

The plot of stress vs rupture time in a log. Scale gives the 10^6 h value or a required shorter value (example: temporary earth fall bridging for 10 min).

Figure 1. Creep rupture test on single rib/strand

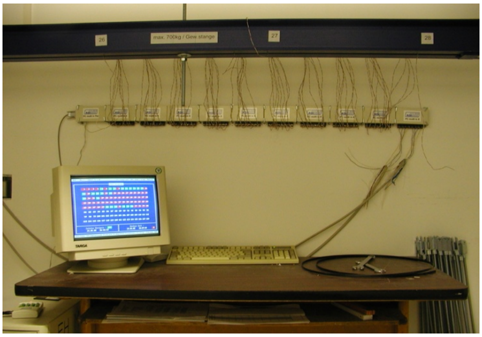

Figure 2. Creep rupture data collecting unit

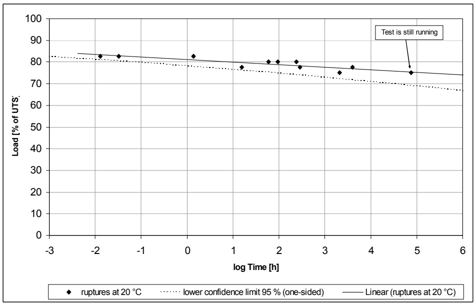

Figure 3. Creep rupture plot PET

Figure 4. Creep and creep rupture of PET

The deformation vs long time under stress is plotted as creep curves (figure 5 PP, figure 6 PET).

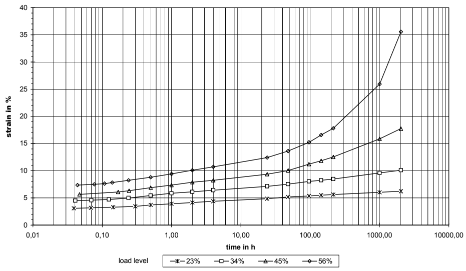

Figure 5. Creep plot PP

Progressive deformation announces the future rupture (or in a plot $\dot{\varepsilon}$ vs ε it is called Onset of rupture -OR-).

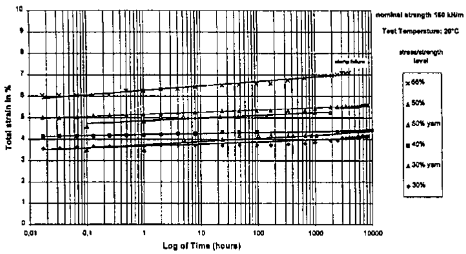

Figure 6. Creep plot PET

To get faster information on deformation behavior for a new polymer, a differently treated fiber or strand the Stepped Isothermal Method -SIM-, first published in 1998 by Scott Thornton, gives the information in shorter time of testing.

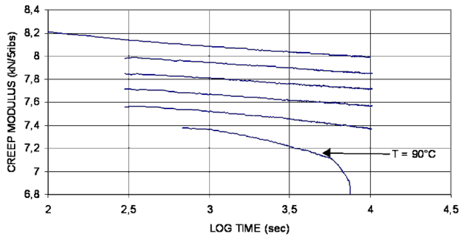

Figure 7. SIM test with single creep curves

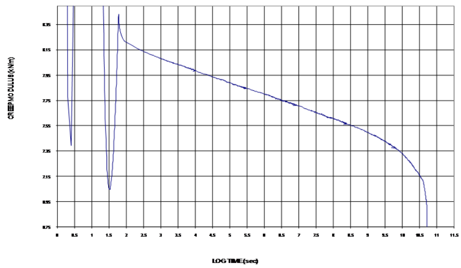

Figure 8. SIM connection of single curves

3 CREEP RUPTURE AFTER INSTALLATION DAMAGE

Geosynthetics are challenged by sharp stones, heavy compaction equipment, vibration when placed on site and then covered by fill soil. The residual strength after this procedure is determined by site tests and site simulation tests in laboratories. We found two main damaging procedures: cut strands by sharp stones and notching of fibers by embedded fine (sharp) particles.

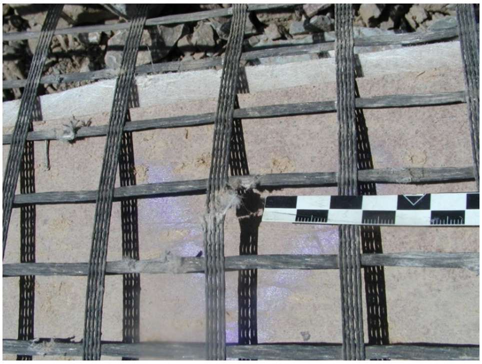

Figure 9. Damaging by cut strands

Figure 10. Damaging by embedded particles

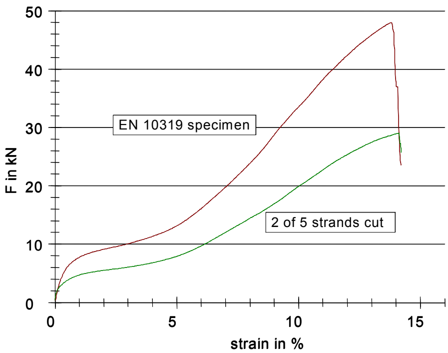

Figure 11. Force-strain curve for cut strands

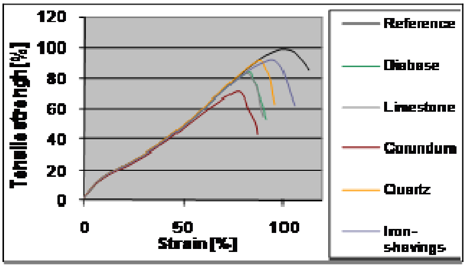

Figure 12. Force-strain curve for embedded particles

Figure 11 and 12 show typical figures of force-strain curves for cut strands (figure 11) and embedded particles (figure 12). With artificial notches creep rupture tests were performed to clear whether there is an additional long term effect by a notch/damage. A huge number of creep rupture tests in a research program show evidence that the long term behavior is not changed (figure 13).

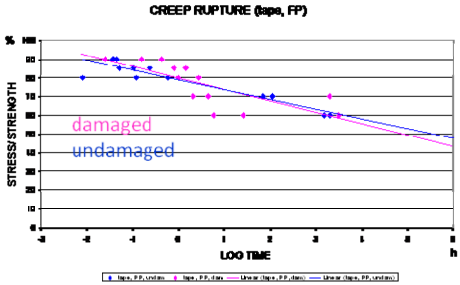

Figure 13. Creep rupture curve for undamaged and damaged PP-tapes

4 FATIGUE AT CYCLIC LOADING

Railroads, roads, airport take off and landing strips as well as taxi ways get regular cyclic loading. The highest number of heavy loads is expected at highly frequented railroads. In the thesis of Dr. Retzlaff the fatigue behavior of the main geosynthetics was investigated. According to measurements on German railroads a loading frequency of 10 Hz was estimated to be relevant (higher frequencies are severely attenuated in soil by particle friction) and a number of 10 million cycles represents 30 a of an intensively used railroad track. The applied load was the sustainable

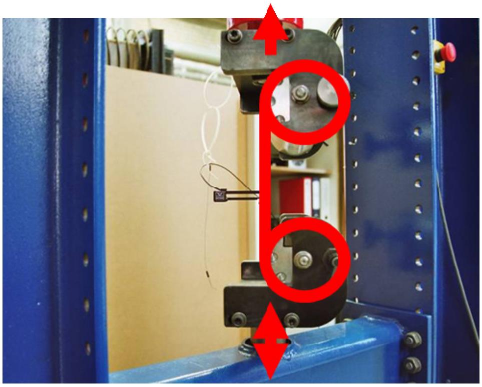

Figure 14. Dynamic test rig

static load for the duration of the fatigue test (ca 12 days) taken from the creep rupture curve. The ratio

$$R = \frac{\min \sigma}{\max \sigma} = 0.66 \text{ ie } 2/3 \text{ static, } 1/3 \text{ dynamic}$$

Some result graphs show the creep during the fatigue test.

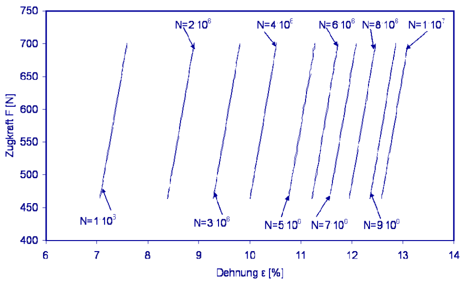

Figure 15. Force strain curves during 10 M cycles for PP

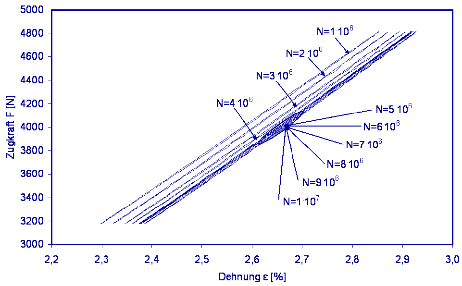

Figure 16. Force strain curves during 10 M cycles for PET

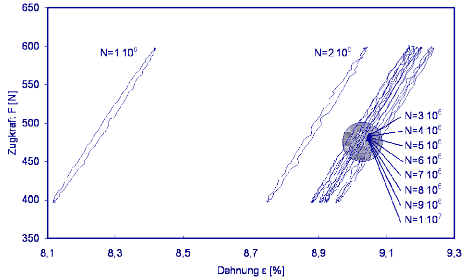

Figure 17. Force strain curves during 10 M cycles for HDPE

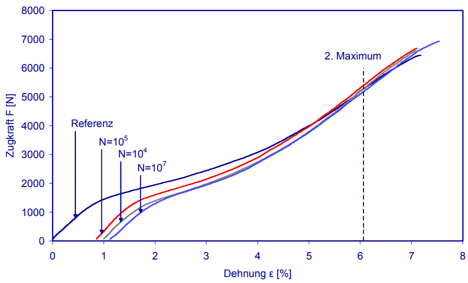

Figure 18. Force strain curves up to rupture after different numbers of cycles for PET

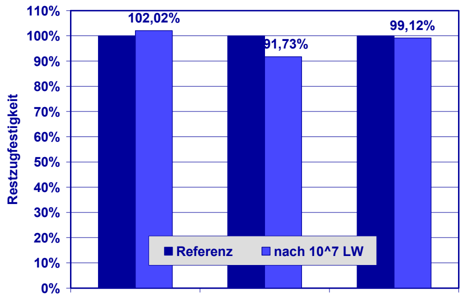

Figure 19. Residual force after 10 M cycles for PET, HDPE, PP

5 CHEMICAL DEGRADATION

Limiting factors in the polymers used are for polyolefins the thermo-oxidation and for polyester the hydrolysis.

5.1 Thermo-oxidation

Polyolefins (PE, PP as the mostly used) tend to add oxygen to their molecule chain-ends and this oxidative process is accelerated by temperature (thermo-oxidation). The process is delayed by additives (as HALS = hindered amino light stabilizer). Oven tests at temperatures of 80 to 110 °C were common to test thermo-oxidation. Results of thin fibers and bigger strands show a clear geometry influence as the process is connected to the surface/volume ratio. This was the reason for Hartmut Schröder et al to develop an accelerated oxidation test with low (or no) influence of geometry of specimen. Publications at Eurogeo 2, Bologna, gave first information and in following conferences it became clear that there is a strong tool to evaluate the thermo-oxidative degradation by the autoclave test. The example contributed by Dr. Retzlaff/Mr. Koroliuk shows test results gained in the tBU and the Arrhenius calculation resulting in 160 years at temperatures of 25 °C for the normal oxygen content in air.

Figure 20. Autoclave rig

Figure 21. Multiple autoclave rigs

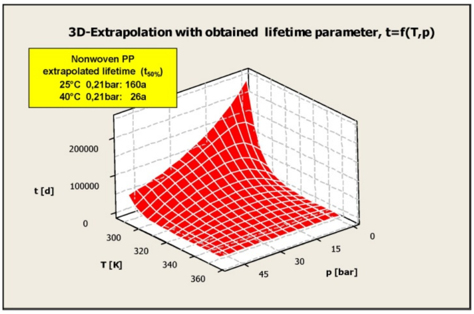

Figure 22. Extrapolation of different autoclave tests (pressure and temperature varied)

5.2 *Hydrolysis*

Polyester in contact with concrete is exposed to pH-values around 12.5. In this alkaline environment water molecules are implemented in the PET-molecules, cutting large molecules, creating higher numbers of carboxylic end groups (CEG) and a smaller molecular mass M_n. To get also for this environment service life estimations, tests in saturated solutions of $Ca(OH)_2$ at temperatures of 20, 50, 60, 70, 90 °C were performed. The time to 50 % residual stress is taken from the result graphs.

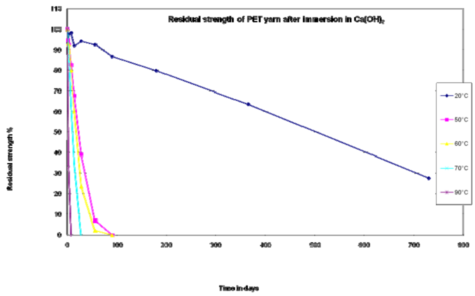

Figure 23. PET yarn immersed in $Ca(OH)_2$

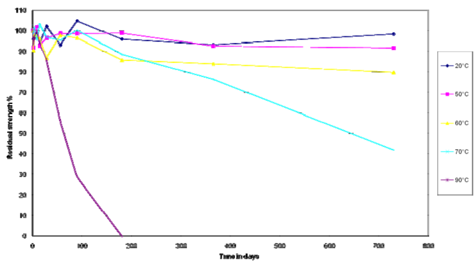

Figure 24. PET yarn immersed in H_2O

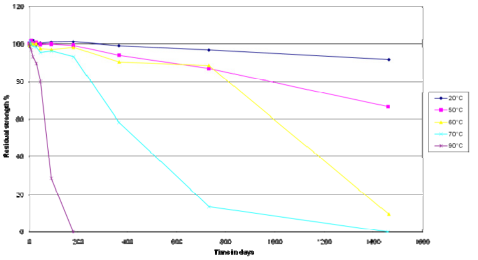

Figure 25. PET strand immersed in $Ca(OH)_2$ for 4 years

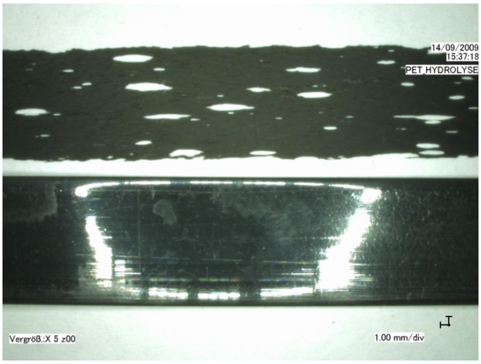

Figure 26. PET strand before and after immersion for 4 years in $Ca(OH)_2$

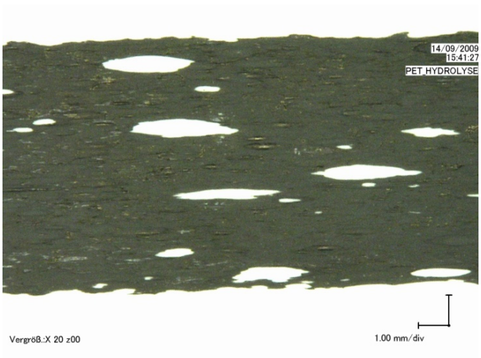

Figure 27. PET strand after immersion for 4 years in $Ca(OH)_2$

Taking the time and temperature values an Arrhenius calculation is possible to get reliable values for a service life estimation. Comparing tests with different polymers (characterized by M_n and CEG-No) show positive influence of a higher M_n.

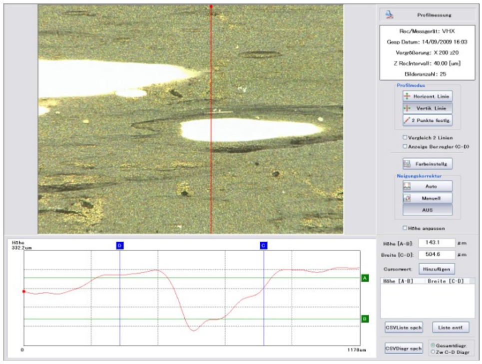

Figure 28. PET strand before and after immersion for 4 years in $Ca(OH)_2$ with profile of surface

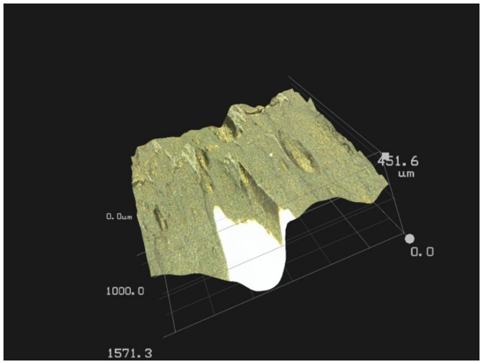

Figure 29. PET strand after immersion for 4 years in $Ca(OH)_2$ 3 D view

Microscopic pictures of the degraded strands show that the hydrolytic degradation is not a pure surface degradation. There are groves holes and structures in the polyester, which resist evidently differently to the alkaline attack.

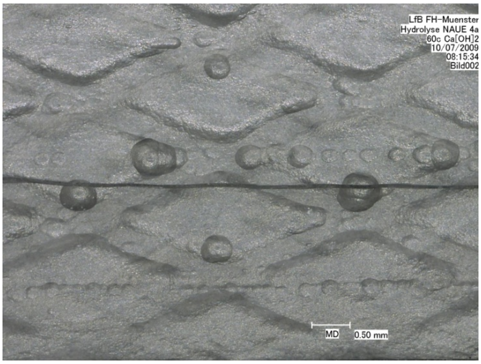

Figure 30. PET strand with higher M_n after immersion for 4 years in $Ca(OH)_2$

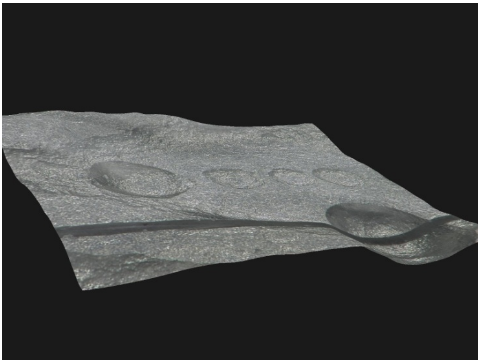

Figure 31. PET strand with higher M_n after immersion for 4 years in $Ca(OH)_2$ 3 D view

6 CONCLUSION

Most aspects influencing the long term performance of geosynthetics can be tested in single purpose tests. Results are shown, extrapolation using Arrhenius equation leads to plausible estimations.

REFERENCES

Koslowski, C. & Müller-Rochholz, J. 1996. Creep prediction, *First European Geosynthetics Conference and Exhibition*, Maastricht.

Müller-Rochholz, J. & Kirschner R. 1990. Creep of geotextiles under different ambient temperature , *4. Int. Conference on Geotextiles, Geomembranes Related Products*, Den Haag.

Müller-Rochholz, J. & Jas, H. & Harting, U. 1994. Effect of Traffic Loading on the Long-Term Behaviour of Geogrids, *5th Conference on Geotextiles, Geomembranes and Related Products*, Singapore.

Müller-Rochholz, J. 1992. Geotextiles in Environmental Engineering. *Symposium on geotextiles in environmental engineering*. Institute of Engineering in Malaysia, Kuala Lumpur, Bangkog.

Müller-Rochholz, J. 2008. Testing the limits *Contribution to symposium oft the igs – International Geosynthetic Society*, Česká republika, Prag.

Müller-Rochholz, J. & Alexiew, D. & Recker, C. & Lothspeich, S.E. 1998. Coated PET-geogrids, wovens and yarns – comparison of longtime performance under tension. *6. International Conference on Geosynthetics,* Atlanta.

Müller-Rochholz & J.; Heerten, G. & von Maubeuge, K. 2000. Long-term performance of geosynthetic drainage systems with filter components. *3. International Conference on Filters and Drainages in Geotechnical and Environmental Engineering*, Warschau.

Müller-Rochholz, J. & Bronstein, Z. 2000. Long-term behavior of geodrain composites in landfill capping – results of exhumations. *2nd European Geosynthetic Conference*, Bologna.

Müller-Rochholz, J. & Bronstein, Z. & Schröder, H.F. & Zeynalov, E.B. & von Maubeuge, K.P. 2002. Long-term behaviour of geosynthetics drains – excavations on landfills after up to 12 years service. *7. International Conference on Geosynthetics*, Nice.

Müller-Rochholz, J. & Bronstein, Z. & Recker, C. & Diederich, R. 2006. Influence of geotextile filters on the discharge capacity of geocomposite drainage materials in long term tests with soil contact. *8th International Conference on Geosynthetics*, Yokohama, Japan.

Pinho Lopes, M. & Recker, C. & Müller-Rochholz, J. & Lopes, M.L. 2000. Installation damage and creep of geosyntetics and their combined effect - experimental analysis. *2nd European Geosynthetic Conference*, Bologna.

Pinho-Lopes, M. & Recker, Ch. & Lopes, M.L. & Müller-Rochholz, J. 2002: Experimental analysis of the combined effect of installation damage and creep of geosynthetics – new results. *7. International Conference on Geosynthetics*, Nice.

Recker, Ch. & Müller-Rochholz, J.. 2002. Comparison of wide width and single rib tests with different clamping sytems. *7. International Conference on Geosynthetics,* Nice.

Retzlaff, J. & Staubermann, C. & Müller-Rochholz, J. 2007. 100 years service life of reinforced geotechnical structures. *3rd international conference lifetime-oriented design concepts*, Bochum/Germany, Freiburg: Aedificatio Publishers.

Schröer, S. & Thornton, J. S. & Müller-Rochholz, J. & Recker, C. 2000. Stepped isothermal method to determine a combined reduction factor for creep and installation damage. *2nd European Geosynthetic Conference*, Bologna.