Long-term resistance to oxidation of PP and PE geotextiles

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ABSTRACT: Geotextiles are products manufactured of polymeric resins and are used in various applications such as separation, filtration, protection, drainage, reinforcement, or erosion control. Geotextiles not only have a large application variability. They also can replace thick mineral components and therefore reduce costs. To ensure the long-term durability, PP and PE geotextiles should be protected against possible influencing conditions, such as oxidation, high temperatures and/or UV. Stabilisers can be used to give sufficient protection. This paper will specifically focus on the investigation and testing of the oxidation influence on PP and PE geotextiles and provide information on various test procedures. The testing conditions for this evaluation were differing percentage of oxidation, changing temperature and/or various pressures. Out of testing data the long-term behaviour of various geotextiles is evaluated and the long-term performance expectation for different applications is estimated also using the Arrhenius model. This paper shows that under realistic testing conditions the service life prediction of PP and PE geotextiles is in the range of several hundred years and there are various conservative ways of determining these results.

1 INTRODUCTION

Geosynthetics are products manufactured from synthetic raw materials and typically used in applications to fulfil separation, filtration, protection, drainage, reinforcement, sealing and erosion control functions. Due to their versatility, these polymer materials have gained an increasing role in geotechnical applications by:

- replacing soil/mineral construction materials – conserving scarce resources
- reducing construction costs
- speeding the construction process
- making innovative construction methods possible

The mechanical behaviour of thermoplastic polymers is primarily influenced by temperature and the compressive load. Furthermore, the performance characteristics and properties of polymers are not fixed, but tend to have a performance "range". Material properties can be considerably influenced by unique differences in the raw material (such as molecular weight and molecular weight distribution) as well as through different additives (Brummermann 1997). Geosynthetics are mostly produced from polypropylene (PP) or high density polyethylene (HDPE) resins. Polyester (PET) is also commonly used for reinforcement products. Typical properties of various polyolefin (PP, HDPE) materials are illustrated in Table 1.

Table 1. Properties of HDPE and PP (Domininghaus 1998)

properties	HDPE	PP
density in g/cm³	0,94 to 0,96	0,90 to 0,92
Temperature of use (maximum, short-term)	90 to 120	140
Temperature of use (maximum, long-term)	70 to 85	100
melting temperature of the crystallites in °C	125 to 135	160 to 165
Vicat – softening temperature in °C	60 to 77	70 to 130

To ensure the long-term performance of geosynthetic materials, they must be protected from the potentially harmful effects of UV radiation as well as thermal and oxidative degradation (for UV stability see flyer "UV resistance of geotextiles" (Naue Fasertechnik 1998)). By adding stabilisers, these ageing processes can be stopped, or greatly reduced. The type of stabilisers (e. g. carbon black for UV resistance) and the amount added within a certain range can considerably improve the long-term performance of the geosynthetic material. For instance, in a thermo-oxidative ageing reaction, the mechanical properties of unstabilised synthetics are affected in the medium-term. This process is not reversible and can be compared with the corrosion of steel. In 1982, Wisse et al. reported on the thermo-oxidative degradation of synthetics and demonstrated through application of an oven test and the Arrhenius model, how one can predict long-term behaviour from short-term tests. Since short-term tests are principally conducted under higher temperatures, oxygen pressures and/or concentrations (influence see Figure 3), and as the ageing reaction proceeds considerably slower in actual soil conditions, short-term tests tend to be conservative (Wisse et al. speak of an additional safety factor of 4 to 10).

It should be noted that the service life is not only defined by changes to the base polymer properties, but also by the dimensional proportions of the geosynthetic and the other occurrences to the material that may take place during the planned service life. To determine the suitability of a geosynthetic for use in an application, the service life can be predicted as in the following model.

2 DESCRIPTION OF THE AGEING BEHAVIOUR

In chemistry, the Arrhenius model has been used since the middle of the last century to explain the exponential relationship between the reaction speed or time, and the temperature for the chemical reaction of gases (Lewen 1991).

The function is as follows

$$\lambda = A \cdot e^{(E/R \bullet T)} \qquad (1)$$

λ = coefficient for the reaction speed
A = empirical factor
R = general gas constant
E = energy content of the reaction speed
T = absolute temperature in Kelvin
t = time

The Arrhenius relation may also be used to describe the time-temperature-displacement of mechanical properties of partially crystalline synthetics between the glass transition and crystallite melting temperature phases – the service temperature range. By taking the logarithm of the Arrhenius relation, the following dependency between the time "t" and the corresponding test temperature "T" is obtained:

$$\ln (1/t) = \ln A - (E/R \cdot T) \quad (2)$$

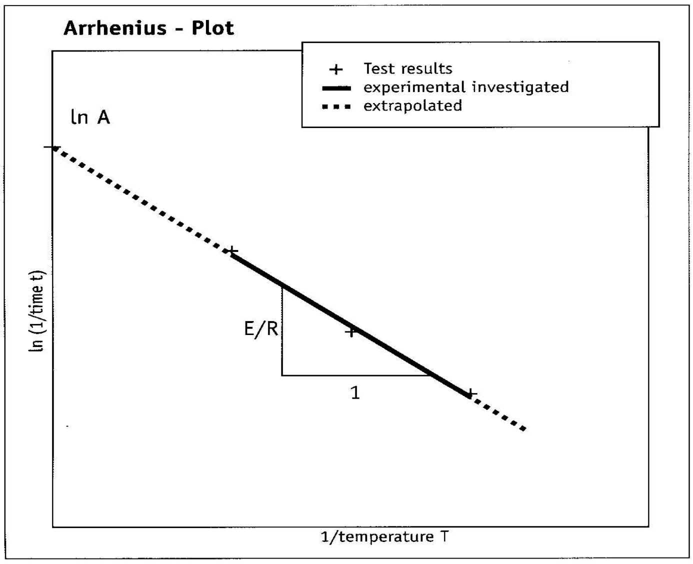

Figure 1. General drawing of the Arrhenius Plot.

Figure 1 illustrates the natural logarithm of the reciprocal value of the time, dependent on the reciprocal value of the temperature, i. e. equation 2. The result is termed the Arrhenius Plot, with the gradient –E/R and the axis section lnA. With a linear Arrhenius plot, long-term characteristics can be predicted from short-term tests at higher temperatures while short-term characteristics can be extrapolated at lower temperatures. However, if the material behaviour is principally different under various temperature ranges, the extrapolation can be limited.

Koerner et al. (1992) further explain the Arrhenius relation and show examples of use for predicting physical and chemical properties of geosynthetics.

3 TEST RESULTS

The CEN standard draft prENV IO 13438 of 1998 requires specimen storage in a warm air oven when testing for the service life of geosynthetics. It is therefore assumed that the subjected geosynthetic is suitable if the product does not fall short of a defined maximum strength or does not have a reduction in its elongation over a given testing period. The testing conditions for polypropylene (PP) and high density polyethylene (HDPE) raw materials are listed in Table 2. A minimum service life of 25 years is ensured if the strength and/or elongation values are reduced by no more than 50 % under given testing conditions.

Table 2. CEN prENV ISO 13438, test conditions for determining a minimum service life of 25 years.

	PP	HDPE
test temperature	110 °C	100°C
testing period for reinforcement applications	28 days	56 days
all other applications	14 days	28 days

Applying this to the testing of geosynthetic materials, a higher expected service life can be determined (Table 3) by increasing the duration of the testing periods presented in Table 2. The expected service life will proportionately increase as the testing period increases, provided that the loss of strength in all cases remains less than 50 % (e. g. double the test period, double the expected service life).

Table 3. Expected service life of PP and HDPE geosynthetics via longer duration tests – according to prENV ISO 13438.

Reinforcement Applications		
test time	PP	HDPE
14 days		
28 days	> 25 years	
56 days	> 50 years	> 25 years
112 days	> 100 years	> 50 years
224 days	> 200 years	> 100 years

All other applications		
testing period	PP	HDPE
14 days	> 25 years	
28 days	> 50 years	> 25 years
56 days	> 100 years	> 50 years
112 days	> 200 years	> 100 years
224 days	> 400 years	> 200 years

To determine the expected service life of various geosynthetic products, Naue Fasertechnik GmbH & Co. KG had tests performed at the TNO (Institute of Industrial Technology) in the Netherlands. The TNO was chosen to perform these tests since J. D. M. Wisse and others had developed the oxidation at the TNO, and due to their experience in handling and evaluating results from complex testing technology. The first results are presented in Table 4.

Table 4. Minimum expected service life according to prENV ISO 13438 of several nonwovens from Naue Fasertechnik (* Depotex® and Secutex® nonwovens – manufactured from fibres as described in certifications of the BAM and DIBt).

product	type of temperature	test temperature	testing period	product	residual strength	residual elongation	expected service life (no reinforcement application)
351-GRK 5	PP standard	110 °C	14 days	351-GRK 5	95 %	104 %	
351-GRK 5	PP standard	110 °C	28 days	351-GRK 5	< 50 %	< 50 %	25 to 50 years
R 301	PP	110 °C	112 days	R 301	78 %	79 %	>> 200 years
RZ 1331	PP*	110 °C	224 days	RZ 1331	90 %	90 %	> 400 years
R 405	HDPE	100 °C	112 days	R 405	57 %	59 %	> 100 years
RZ 1335	HDPE	100 °C	224 days	RZ 1335	80 %	80 %	> 200 years

Tests marked with >> have exceeded the indicated test time and continue.

The results of the ageing tests presented in Table 4 clearly indicate that fibres from high quality resins have a service life of more than 100 years, without significant loss of strength. This high quality is defined in certifications from the Federal Institute for Material Research and Testing (BAM), and the German Institute for Construction Technology (DIBt). Considering the safety factor of 4 to 10 (as defined by Wisse et al.) for the ageing processes actually occurring in a soil environment, a geosynthetic correctly manufactured with high quality resins could be predicted to survive the expected service life for reasonably long time periods.

PP resin supplier DSM defined the brittle point of PP as a function of the temperature and the specimen thickness for dimensions of 3.0 mm and 1.0 mm (Gijsman 1994). Figure 2 presents the results and suggests that the 1 mm specimen (thickness of monofilament of the Secudrän® drainage core) has a service life of more than 400 years at a temperature of 20° C. Since temperatures range between 0° to 20° C in soil depths of up to 1 m, a substantially longer service life can be expected.

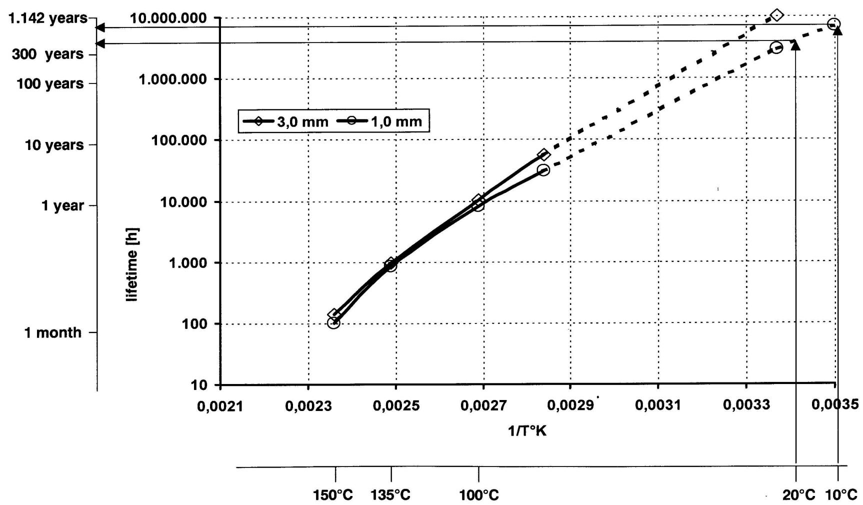

Figure 2. Service life of polypropylene used in Secudrän® drainage cores according to the Arrhenius model.

Further investigations of the oxidative influence on polyolefins (PP, HDPE) were conducted in the past by Salman et al. (1998). In oxygen conditions modelled after soil of approx. 8 % and at a temperature of 20° C, it was shown that PP nonwoven fabrics can have an expected service life of approximately 240 years (Figure 3) when assuming a maximum loss of strength of 50 %.
Figure 3. Arrhenius plot for a polypropylene needle-punched nonwoven, determined under various temperature and oxygen concentrations at 50 % residual strength.

At an ambient temperature of 10° C, a service life of more than 500 years can be expected from these test results. This supposition is supported by the tests of Wisse et al., who concluded that short-term tests under higher oxygen concentrations and/or pressures lead to comparatively conservative results.

Hence, several independent investigations have come to similar and extremely positive results regarding the long-term performance of geosynthetics. The latest investigations (Christopher et al. 1999) on geosynthetics that have been exhumed after 30 years of service indicate no evidence of ageing and substantiate the findings gained so far (Heerten 1981, SVG 1998, Ehrenberg and von Maubeuge 1999).

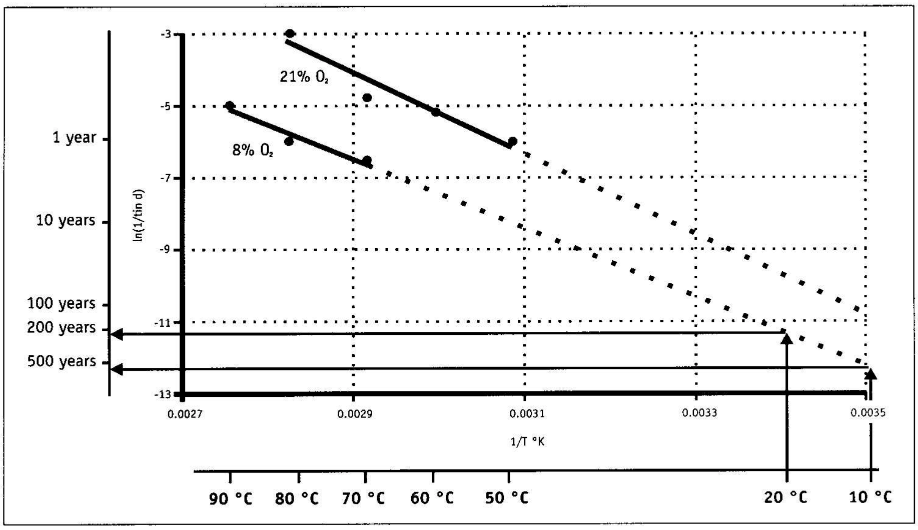

Figure 3. Arrhenius plot for a polypropylene needle-punched nonwoven, determined under various temperatures and oxygen concentrations at 50 % residual strength (Salman et al.).

4 CONCLUSIONS

Geosynthetics are utilised in a range of applications including landfills, road and hydraulic engineering separation, filtration, protection, drainage, reinforcement, sealing and erosion control functions and must therefore be manufactured to withstand the expected service life of the design. In the CEN standard draft prENV ISO 13438, test conditions are presented that allow for the determination of the expected geosynthetic service life. Unless the strength and elongation values of the polypropylene raw material are reduced by more than 50 % after 28 days at a test temperature of 110° C, the standard draft assumes a minimum service life of 25 years for reinforcement applications. For all other applications this 50 % reduction value must not be exceeded after 14 days. Although HDPE is tested at a test temperature of 100° C, the maximum value of 50 % must not be exceeded after 56 days of reinforcement applications (28 days for all other applications).

Employing the Arrhenius relation as the basis for determining longer-term characteristics, it is possible to extrapolate performance from short-term tests in soil-like temperature conditions and to make more realistic service life predictions. Preliminary data from the TNO indicate that the standard polypropylene fibre style used has an expected conservative service life of at least 25 to 50 years (under the actual occurring ageing process according to Wisse et al. four times longer; 100 to 200 years).

The standard HDPE fibres used for the nonwoven fabrics reach expected service lives of more than 100 years.

The high quality fibres used in the other nonwoven fabrics show substantially higher service life for non-reinforcement applications. This fibre has been granted BAM and DIBt certifications.

According to knowledge gained so far, the extrapolated values predict a service life of more than 200 years. The 1 mm thick entangled monofilaments of the drainage core reach an expected service life of more than 300 years.

While these tests were carried out under increased oxygen concentrations, Wisse et al. determined in 1982 that the oxidation tests conducted are more likely to be conservative. It can therefore be expected that geosynthetics in soil surroundings will achieve a higher service life than extrapolated from the short–term tests (four to ten times).

REFERENCES

Brummermann, K. 1997. Schutzschichten für Kunststoffdichtungsbahnen in Deponiebasisdichtungen – Prüfung und Bewertung ihrer Wirksamkeit (Protection Layers for Geomembranes in Landfill Lining Systems – Testing and Assessment for the Efficiency). *Thesis at the University of Hanover*. Germany

CEN, European Committee for Standardisation. 1998. prENV ISO 13438 – Geotextiles and geotextile-related products – Screening test method for determining the resistance to oxidation (ISO/DTR 13438:1998). Brussels. Belgium.

Christopher, B. R., Valero S. N. 1999. Thirty-Year Performance Evaluation of a Geotextile Filter. *Geosynthetics '99*. Boston. USA.

Domininghaus. H. 1998. Die Kunststoffe und ihre Eigenschaften (Synthetics and their Properties). 5. Auflage. Springer Verlag, Berlin. Germany.

Ehrenberg, H., von Maubeuge, K. P., 1999. Langzeitbeständigkeit von Geokunststoffen (Long-term Resistance of Geosynthetics). *9. Karlsruher Deponie- und Altlastenseminar,* Karlsruhe., Germany.

Gijsman, P. 1994. The long-term stability of polyolefins. *Thesis at the Technical University of Eindhoven*, the Netherlands.

Heerten, G. 1981. Untersuchung langjährig eingebauter Geotextilien (Investigation on geotextiles with a long service life). *Geotextilien im Wasserbau. Franzius-Institut für Wasserbau und Küsteningenieurwesen der Universität Hannover. Sonderdruck Heft 52,* Hanover, Germany

Koerner, R. M. et al. 1992. Arrhenius Modelling to Predict Geosynthetic Degradation. *Geotextiles and Geomembranes, pp 151 – 183.*

Lewen, B. 1991. Das nicht-linear viskoelastische Verhalten von Kunststoffen am Beispiel der Zeit-Temperatur-Verschiebung und der Querkontraktionszahl. *Dissertation an der Fakultät für Maschinenwesen der Rheinisch-Westfälischen Technischen Hochschule*. Aachen, Germany.

Naue Fasertechnik GmbH & Co. KG. 1998. UV resistance of geotextiles. Lübbecke, Germany.

Salman, A. et al. 1998. The Effect of Oxygen Pressure, Temperature and Manufacturing Processes on Laboratory Degradation of Polypropylene Geosynthetics. *Sixth International Conference on Geosynthetics.* Atlanta. USA.

SVG. 1998. Das Geotextil-Handbuch. Kapitel 12. Langzeitverhalten von Geotextilien (The Geotextile Manual, Chapter 12, Long-term Performance of Geotextiles). St. Gallen, Switzerland.

Wisse, J. D. M., Birkenfeld, S. 1982. The long-term oxidative stability of polypropylene geotextiles in the Oosterschelde Project. *2nd International Conference on Geotextiles.* Las Vegas. USA.