STUDY OF ARTIFICIAL AND OUTDOOR WEATHERING OF STABILISED POLYPROPYLENE GEOTEXTILES

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Abstract: The exposure of non-woven geotextiles to UV light affects their service lifetime considerably. Normally geotextiles have to withstand the attack by UV radiation only for a few weeks until they will be covered with soil or other geosynthetics. The global solar radiation and also the climatic conditions are different in south Europe and in central Europe. Therefore an outdoor exposure at different locations will lead to different degradations of the polymer for the same exposure duration. Since the exposure conditions might change from one year to another year artificial weathering in the laboratory is used to get repeatable data. Additionally artificial weathering is an accelerated ageing method. Therefore, artificial weathering is more useful to get comparative results. However, because different types of apparatus may be used, there is a question as to which method best simulates or gives safe results. In addition, there is the question, what is the equivalent radiation for artificial weathering that relates to a specific climate in e.g. Europe?

In this study three geotextile samples have been exposed at three different outdoor locations, and also in both a Xenon-arc and a fluorescent UV device. The physical properties of the polypropylene non-woven geotextile were the same for all three roll samples, but they have been stabilised with different amounts of additives. The outdoor exposures took place in Germany, in the Netherlands and in south France. The tested specimens have been exposed to UV doses of 45 MJ/m², 90 MJ/m², 135 MJ/m² and 180 MJ/m². After their exposures the mechanical properties have been tested and the remaining contents of the UV-stabiliser were measured. Correlations of the UV dose with mechanical properties and remaining UV-stabiliser content will be shown.

Keywords: ageing, degradation, durability, non-woven geotextiles, polypropylene, weathering.

INTRODUCTION

Geotextiles are typically exposed to weathering for only a short time during construction work. A few weeks of outdoor exposure may dramatically change the properties of the polymer. These changes will also influence the expected service life time of the geosynthetic even if covered under soil.

Because of different climatic conditions in different regions, the results from outdoor exposure cannot exactly be reproduced in a standard test. Also, within the short periods of usage before covered up with soil the intensity of radiation ageing may vary dramatically. In Hamburg for example, the radiation doses may vary by a factor of 10 (Dehne, 2004) each month. Because of that one has to consider a maximum of ageing processes caused by global solar radiation, heat, moisture etc. (worst-case situation). This is primarily important for geosynthetics which are exposed to outdoor conditions for only a short time.

The ability to provide reproducible results is important for an artificial weathering device. Additionally, one has to ensure, that the selected weathering device or method gives a good correlation to the worst case conditions in an outdoor exposure.

In the UV range the energy of the photons is about 3 eV to 4 eV or about 300 kJ/mol to 400 kJ/mol, respectively. This is as high as the dissociation energy of chemical bonds in polymers (Trubiroha 2008). Therefore the action of UV radiation is usually the main degrading agency during outdoor exposure.

The reference spectrum for artificial weathering according to EN 12224 is between 300 nm and 400 nm. In Europe the radiation is between the lowest levels within the Artic Circle and the highest levels in Sicily. The maximum spectral irradiance of global solar radiation will be achieved at clear sky conditions when the sun is in the zenith and the sun's rays take the shortest way through the atmosphere. It is important to notice, that there is no location on earth where the sun is always in the zenith at clear sky conditions.

Additionally, polymers may degrade in outdoor exposures because of pollutants or acidic precipitation in industrial areas. This has been found in outdoor and artificial exposures for polyamide (PA) but not for polypropylene (PP) by Hufenus et al. (2001).

Tabor and Wagenmakers (1992) studied the effect of an UV exposure on the tensile strengths of technical yarns at different climatic conditions. The weathering tests in a fluorescent UV lamp device with constant climatic conditions showed a strong influence of heat on the photo degradation of the PP yarn.

The effect of global solar radiation warms up the specimen surfaces above the temperature of the surrounding air. A dark-coloured surface will be higher in temperature than a light-coloured surface. A measured temperature difference of up to 13°C in the Xenon-arc device correlated well with the data from Arizona. In fluorescent UV lamp devices the temperature difference between white and black surfaces is only around 3°C (Fischer and Ketola 1993).

In fluorescent weathering devices the surfaces temperatures of different coloured samples are, in principle, independent of the irradiance, because of the missing visible and infrared light.

With Xenon radiation the indicated surface temperatures of coloured samples are more realistic in comparison to natural solar radiation especially about the middle of the day (10 a.m. to 2 p.m.).

Regarding special moderate outdoor weathering conditions the temperature differences between white and dark specimen can be higher in Xenon-arc devices as in reality. In fluorescent UV lamp devices the temperature differences are too low in many cases.

Koerner et al. (1998) tested several non-woven geotextiles in outdoor exposure acc. to ASTM D5970 in Pennsylvania, South Carolina and Texas and compared the results with Xenon-arc acc. to ASTM D4355 and fluorescent UV-lamp acc. to ASTM D7238 exposures. They came to the conclusion that fluorescent UV lamps weathering are more severe than Xenon-arc. At settings used in their study the UV irradiance and the temperature were higher in the fluorescent UV lamp device.

TEST PROGRAM

This study comprises tests of samples, which were aged in two different artificial weathering devices and at three different outdoor weathering sites in Europe. For the investigation of the weathering resistance a non-woven PP geotextile type was used. This is a light grey mechanically bonded non-woven with endless fibres with a mass per unit area of 155 g/m². Three identically prepared samples have been tested with three different initial stabiliser contents:

- type 1: standard stabilised
- type 2: high stabilised
- type 3: very high stabilised

The mechanical properties of all three types were the same. From each roll four specimens equally distributed over the roll width have been taken for each exposure condition. Small width specimens of 300 by 50 mm have been used with the orientation in machine direction.

Weathering

After conditioning of 96 hours in standard climate the specimens have been exposed at 5 different conditions (Table 1). Specimens have been taken for testing after reaching a radiation dose of 45 MJ/m^2 each, up to a complete dose of 180 MJ/m² in the spectrum of 300 to 400 nm (UV). As artificial weathering devices have continuous radiation in comparison with outdoor tests based on the same UV dose an acceleration time factor of about 3 to 4 was found (Table 1). In Table 2 the individual durations are given for each UV dose interval of 45 MJ/m².

Table 1. Weathering conditions

Exposure	Test method	Remarks	Total duration of exposure
UVA-340 fluorescent lamps: UV 2000	EN 12224	black standard temperature: 50°C 300-400 nm: 40 W/m² cycle: 5 h dry and 1 h water spray	50 d
Xenon-arc: Suntest XXL+	EN 12224		50 d
Germany	outdoor exposure	5th April to 4th November 2006	214 d
Holland	outdoor exposure	4th April to 1st November 2006	212 d
France	outdoor exposure	6th April to 15th September 2006	163 d

Table 2. Individual exposure durations in hours (approximate values)

UV doses [MJ/m²]	Fluorescent lamps	Xenon-arc	Germany	Holland	France
45	300	300	1200	1200	1100
90	600	600	2300	2300	2000
135	900	900	3200	3300	3100
180	1200	1200	5100	5000	3900

Artificial weathering

Fluorescent UV lamps provide a radiation only in a wavelength range between 300 to 400 nm. However, the spectrum of a Xenon-arc device corresponds well with the solar radiation in the whole wavelength range. Therefore, it may be possible that different ageing processes will occur.

For ease of comparison, all the degree of exposure of weathering processes ought to be represented as a function of the radiant exposure in MJ/m² (energy per surface). If only test durations are considered, variations of the intensity of radiation (being the main influencing factor for ageing processes) are not taken into account (Hufenus et al. 2001).

The test procedure and the corresponding test parameters for the determination of the weathering resistance of geotextiles are described in EN 12224. These test parameters were used for the artificial weathering tests.

Outdoor weathering

The results of natural weathering tests are subject to highly variable conditions regarding radiation, climate and pollutants (in time and locally) are hardly reproducible. In order to validate the tests results of the artificial weathering three locations for outdoor exposure tests have been chosen in Würzburg (Germany) at an altitude of about 177 m, Hoek van Holland (Netherlands) at an altitude of about 0 m and Sanary-sur-Mer (south France) at an altitude of about 30 m. The specimens were installed on racks with an angle of inclination of 45° toward south.

The locations in Germany and Holland are characteristic for middle European climate zones and in Sanary-sur-Mer there is a dry south European climate. The measured air temperatures for each location are given in Figure 1 as minimum, average and maximum air temperature for the periods from April to October 2006. The measurements of rainfall are given in Figure 2.

The maximum temperatures in Germany were comparable to France whereas the maximum temperatures in Holland were always lower. On the other side the minimum temperatures were lowest in Germany. Therefore the average temperatures in Germany were lower than in France.

There was nearly no rainfall in France and much more rainfall in Holland and Germany. This means that the exposed specimens were cooled down more during weathering at the middle-European sites. In other words, the temperature of the specimens in France might be considerably higher. As the photo degradation of PP is strongly influenced by heat, temperature is a very relevant issue in the evaluation of the test results from different locations throughout Europe.

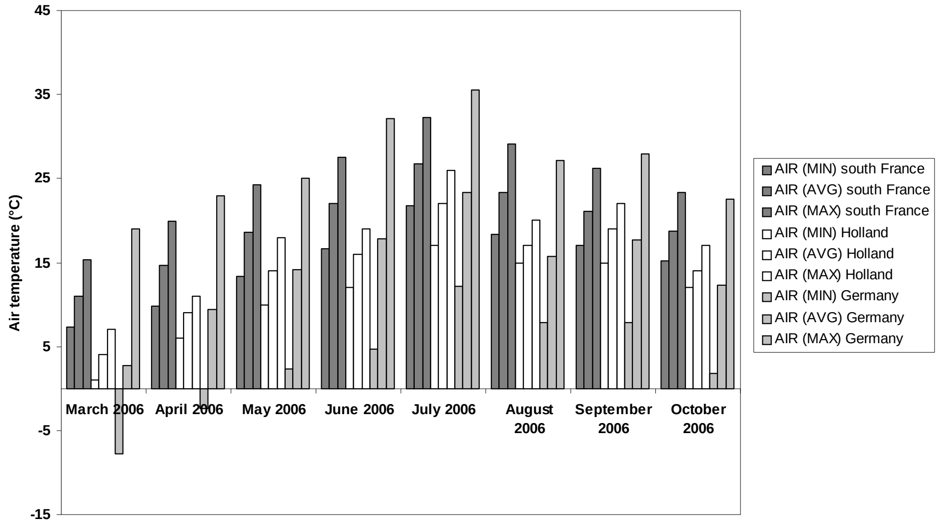

Figure 1. Air temperature measured at 3 different sites for a period of 7 months

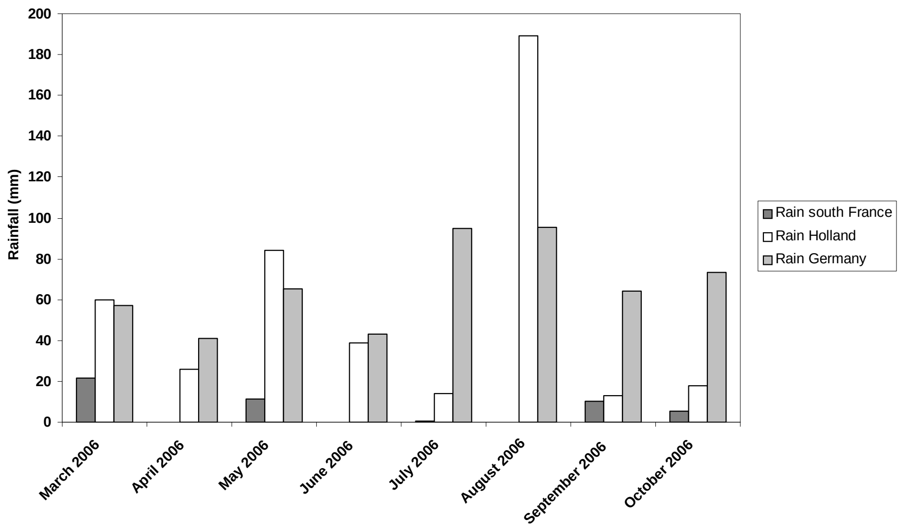

Figure 2. Rainfall measured at 3 different sites for a period of 7 months

Mechanical tests

The mechanical properties of the specimens have been determined in small-width tensile tests following EN 29073-3 in the initial stage and after each UV dose of 45 MJ/m². The measurements have been performed under standard climate conditions. The test speed was 100 mm/min. The free length was 200 mm. Four specimens have been tested for each sample and condition.

Stabiliser content

The investigation of the radiation-caused depletion of the light stabiliser in the polymeric synthetic fibres was determined with a HPLC-method by Ciba Speciality Chemicals. As light stabiliser a hindered amine light stabilizer (HALS) was used.

As the analysis is very costly the measurements of the stabiliser content were limited to single selected specimens. It has to be noticed, that a quantitative determination of the stabiliser after its activation by radiation is more difficult. Therefore, the measured stabiliser contents of the aged specimens should be regarded as comparative measurements. The measurements have been performed on the ruptured specimens after the tensile testing.

RESULTS

Tensile tests

The test results are given as tensile forces and as elongations at rupture. As non-wovens have a certain scattering in mass per unit area, the tensile strength is given in the following figures as maximum tensile forces per specimen weight in Newtons per gram.

In Figures 3 to 12 the tensile properties for the three tested types (standard, high and very high stabilised) are given for each test condition depending on the applied UV dose. The standard deviations of each measurement based on four single specimens are between about 5 to 10%.

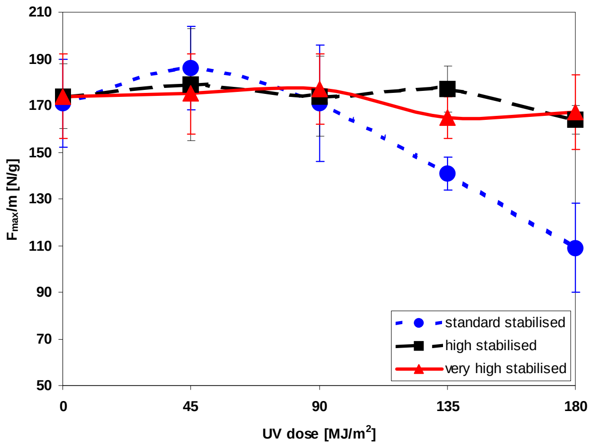

Figure 3. Artificial weathering with fluorescent UV – Standardised maximum tensile force per weight of specimen

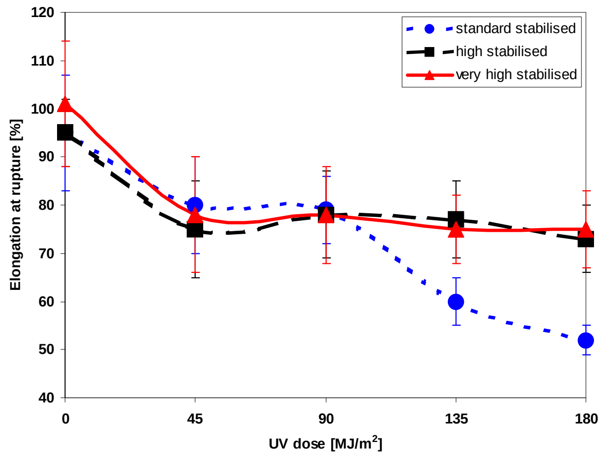

Figure 4. Artificial weathering with fluorescent UV – Elongation at rupture

Figures 3 and 4 demonstrate that the standard stabilised geotextile starts to degrade significantly at 90 MJ/m² in the fluorescent UV lamp device. With the exception of a certain decrease of the elongation at rupture at 45 MJ/m^2, the samples with higher stabilisation show virtually no change of the mechanical properties. Apparently, the initial decrease of the elongation at rupture is an effect, which cannot be related to stabiliser depletion, because it affects all tested types of geotextiles similarly. In general, the geotextiles show an increase of stiffness for all exposures.

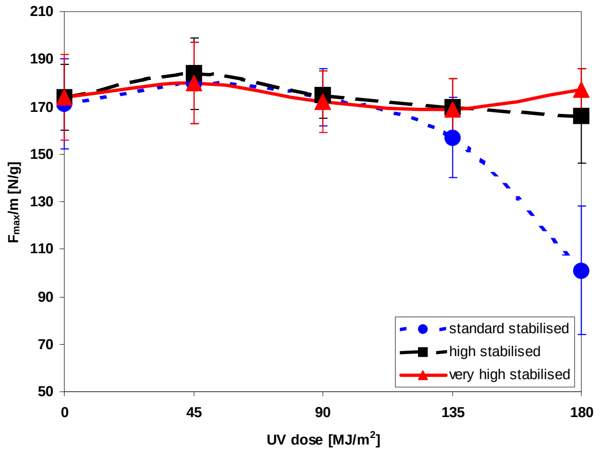

Figure 5. Artificial weathering with Xenon-arc – Standardised maximum tensile force per specimen weight

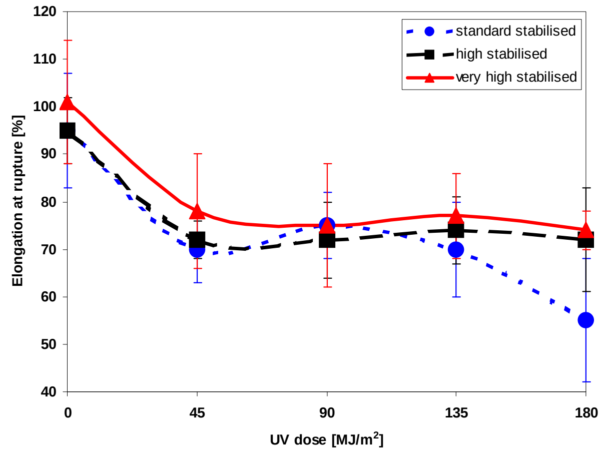

Figure 6. Artificial weathering with Xenon-arc – Elongation at rupture

Figures 5 and 6 demonstrate that the standard stabilised geotextile starts to degrade at 90 MJ/m² in the Xenon-arc device. The samples with higher stabilisation exhibit mostly unchanged mechanical properties. Both artificial weathering devices show similar effects in terms of the mechanical properties of the tested PP geotextiles.

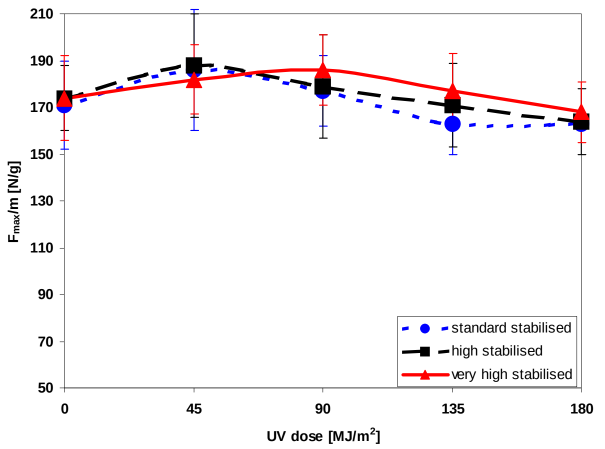

Figure 7. Field exposure in Germany – Standardised maximum tensile force per weight of specimen

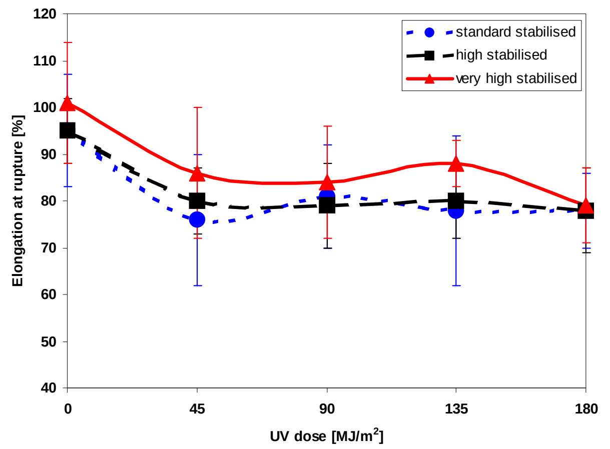

Figure 8. Field exposure in Germany – Elongation at rupture

Figures 7 and 8 show nearly no changes of strengths of any of the tested geotextile types during the exposure in Germany up to an UV dose of 180 MJ/m².

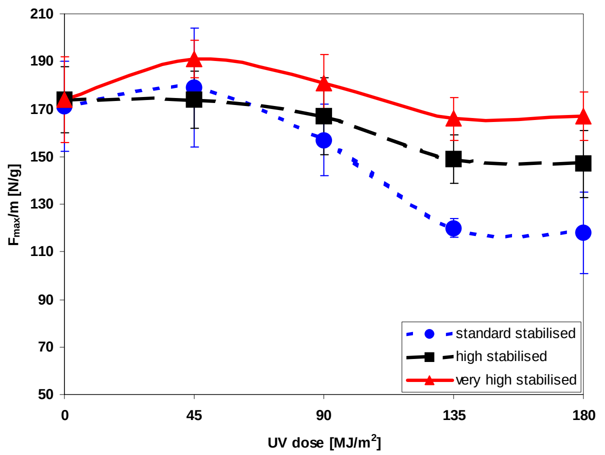

Figure 9. Field exposure in south France – Standardised maximum tensile force per weight of specimen

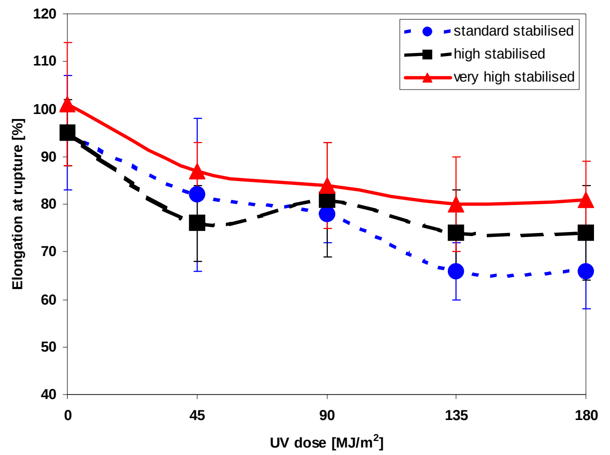

Figure 10. Field exposure in south France – Elongation at rupture

Figures 9 and 10 demonstrate a degradation in the mechanical behaviour for all tested types in south France may be due to higher temperatures in south Europe as discussed above. They start to degrade at 90 MJ/m².

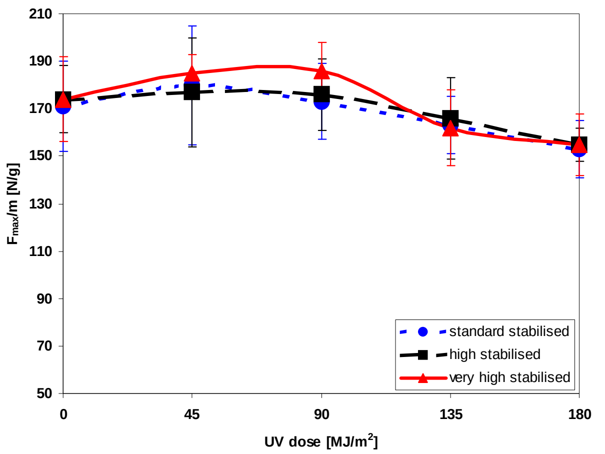

Figure 11. Field exposure in Holland – Standardised maximum tensile force per weight of specimen

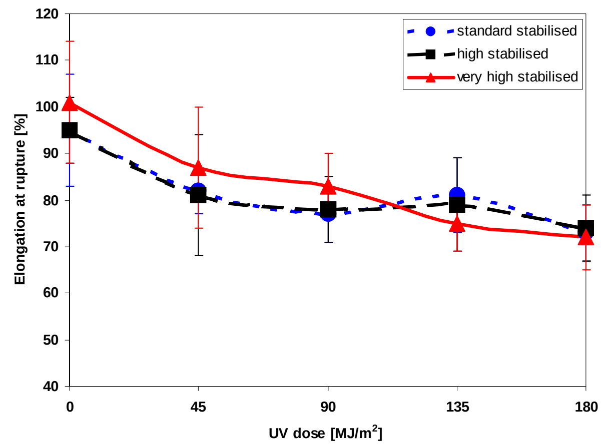

Figure 12. Field exposure in Holland – Elongation at rupture

Figures 11 and 12 show slight degradation in the mechanical behaviour for all tested types in Holland during the exposure up to an UV dose of 180 MJ/m². They start to degrade at 90 MJ/m². The temperature effect might be the reason again for the differences in the test results of the outdoor exposures between Holland and France.

Consumption of stabiliser

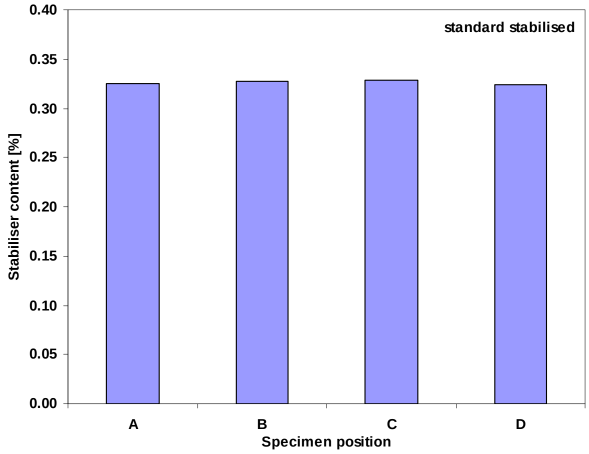

Figure 13. Stabiliser distribution of different samples of the standard stabilised geotextile (initial stabiliser content)

Figure 13 demonstrates that the initial stabiliser content distribution over the roll width of the standard stabilised geotextile was very homogenous.

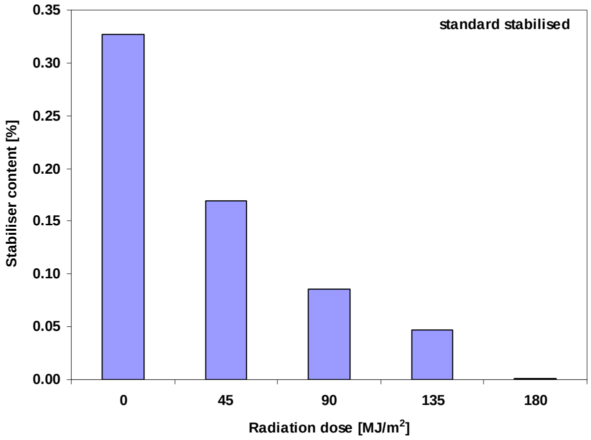

Figure 14. Stabiliser degradation of the standard stabilised geotextile in the Xenon-arc device

Figure 14 gives an indication of the consumption of stabiliser during the exposure in the Xenon-arc device. The consumption of stabiliser in the standard stabilised geotextile is steady.

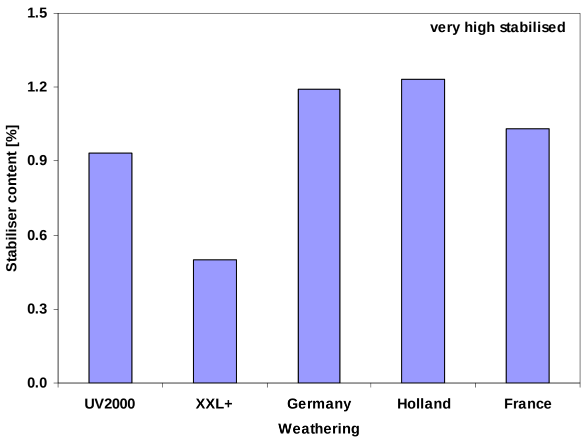

Figure 15. Residual stabiliser content of the very high stabilised geotextile after an UV dose of 180 MJ/m²

In Figure 15 the residual stabiliser content of the very high stabilised geotextile is given in comparison with all test conditions. The highest consumption of stabiliser took place in the Xenon-arc device, which is apparently due to the higher temperature of the test specimens. The residual stabiliser content in the samples exposed to the fluorescent UV lamp device is similar with France. Germany and Holland show similar, higher levels, of residual stabiliser.

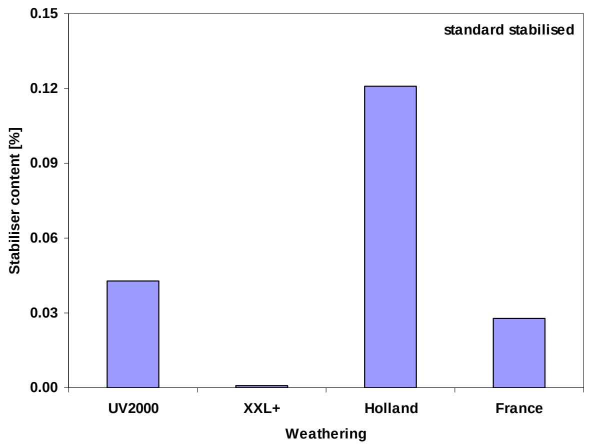

Figure 16. Residual stabiliser content of standard stabilised geotextile after an UV dose of 180 MJ/m²

In Figure 16 the residual stabiliser content of the standard stabilised geotextile is also given in comparison with four test conditions. Again, it can be seen, that the significantly highest consumption of stabiliser took place in the Xenon-arc device. The residual stabiliser content in the fluorescent UV lamp device is similar with France. After the exposition in Holland there is the highest remaining stabiliser content (Note: Due to a contamination the stabiliser content of the samples exposed in Germany could not be measured exactly).

These findings correspond with the measurements of the mechanical properties. Apparently, a “critical” stabiliser content of about 0.1% is needed to prevent a noticeable degradation of this material.

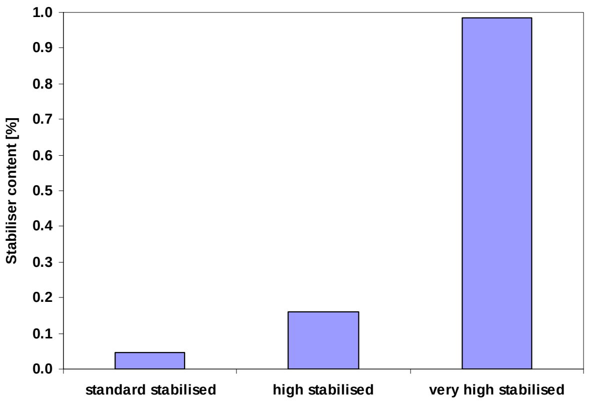

Figure 17. Residual stabiliser content of 3 specimens subjected to different stabiliser percentages after an UV dose of 135 MJ/m² in the Xenon-arc device

Figure 17 shows that the “critical” stabiliser content has been reached for the specimen with standard stabilisation but not for those with high and very high stabilisation. The mechanical properties of the corresponding samples did not change, too (Figures 5 and 6).

CONCLUSIONS

UV exposure may dramatically change the properties of geotextiles. They are typically exposed to weathering only for a short time during construction until they will be covered with soil. Results from outdoor exposures cannot be repeated exactly. Therefore artificial weathering is necessary for the determination of the weathering resistance. The worst case situation has to be considered. This means that artificial weathering tests should simulate all possible ageing processes which may be caused by global solar radiation, heat and moisture. The maximum spectral irradiance of global solar radiation will be achieved at clear sky conditions when the sun is in the zenith and the sun’s rays take the shortest way through the atmosphere. However, there is no place on earth where the sun is always in the zenith with a clear sky conditions, as simulated by artificial weathering devices.

The second important factor which governs the ageing of the geotextiles in a weathering study is the temperature, especially when the fibres are made of PP. Heat will strongly influence the kinetics of photo degradation of PP. The action of global solar radiation warms up the specimen clearly above the air temperature. It is known that in a Xenon-arc devices the maximum temperature differences between the surface of the specimen and the surrounding air is up to 13°C whereas in fluorescent UV lamps device it is only up to 4°C (Fischer and Ketola 1993).

The temperature differences in Xenon-arc devices of coloured samples more closely simulate natural solar radiation than fluorescent UV devices, which show nearly no temperature difference. Since Xenon-arc simulates the worst-case situation the actual surface temperatures of the light-grey non-woven geotextiles in the Xenon-arc test device are higher than in Würzburg, Hoek van Holland and Sanary-sur-Mer. On the other hand correlation or comparison of outdoor data with artificial weathering data should consider several years of testing. So the presented test results show trends which have been considered very carefully. An artificial weathering test procedure can be designed to simulate worst-case conditions or specific climate locations concerning the relevant climate factors.

Therefore, one type of artificial weathering device cannot simulate all natural outdoor conditions. In general the conditions in an artificial weathering test are oriented more to the situation in south Europe than to locations in middle or north Europe.

This study shows that the artificial weathering in a fluorescent UV device and in a Xenon-arc device provide similar degradation of the mechanical properties of stabilized PP geotextiles. The consumption of light stabiliser is higher in the Xenon-arc device, which is probably due to the higher surface temperature.

The outdoor weathering tests show a comparable degradation behaviour in Germany and in Holland, but a stronger degradation in France. Again, these results may be attributed to the more severe climatic conditions in south Europe where the average temperatures were higher and the rainfall was considerably lower than at the more northern sites.

Both artificial weathering devices show a good simulation of the worst case situation of south Europe. Because of the higher temperature in a Xenon-arc device the consumption of light stabiliser is faster. The temperature in an UV lamp device is lower in general. These effects and also the influence of the colour of the geotextiles should be taken into account by weathering tests, especially for geotextiles made of PP.

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