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UV STABILITY OF POLYPROPYLENE
STABILITE AUX U.V. DE POLYPROPYLENE
UV-BESTÄNDIGKEIT VON POLYPROPYLEN

It is a well-known fact that plastics degrade under the influence of sunlight, water, temperature and oxygen, if not properly stabilized. Protection of polypropylene against influence of the UV section of the sunlight can be obtained by professional use of proper UV stabilizers in order to prevent this degradation.
Since outdoor exposure tests would take too much time, weathering devices have been developed to provide accelerated weathering tests. In this paper accelerated test methods are described and a correlation has been established between the accelerated weathering test in a Xenotest 1200 and the outdoor exposure of the same fabrics. By using this test, a method is available to obtain comparable UV stability data for different types of fabrics, which can facilitate specification and ultimate choice of a fabric on a project.

Es ist ein allgemein bekannte Tatsache, dass sich Kunststoffe unter dem Einfluss von Sonne, Wasser, Temperatur und Sauerstoff verändern.
Auch Polypropylen baut durch UV-Strahlung ab. Durch den Einsatz geeigneter UV-Stabilisatoren kann jedoch der Abbau um lange Zeit verzögert werden. Da die Prüfung der Materialbeständigkeit durch Freibewitterung zu lange dauern würde, wurden Geräte zur künstlichen Bewitterung entwickelt, die den Abbau beschleunigen. In dieser Ausführung sind Methoden zur Durchführung der künstlichen Bewitterung beschrieben. Ein Zusammenhang zwischen simulierter Bewitterung im Xenotest 1200 und Aussenbewitterung gleicher Gewebe wurde hergestellt.
Bei Durchführung der beschleunigten Bewitterung nach dieser Methode erhält man vergleichbare Werte für die UV-Beständigkeit verschiedener Gewebe. Dies erleichtert Spezifikation und Auswahl von Gewebe für ein bestimmtes Projekt.

1. INTRODUCTION

About 70 % of geotextiles are made from polypropylene, either woven or nonwoven. It is a well-known fact that degradation problems will arise when polypropylene is exposed to environmental conditions, such as sunlight, temperature or oxygen, if not properly and professionally stabilized. This degradation is generally noticed in deterioration of physical properties, such as tensile strength and elongation. Therefore it is of paramount importance to list all requirements and then develop a tailor-made product which meets the specific end use.

2. AGEING PROCESS

In the main, ageing of polymers is caused by the UV section of the light. Polypropylene has its maximum photochemical sensitivity at a wave length of 370 nm, polyethylene at 300 nm, polyester at 325 nm. Under the influence of oxygen an activation energy of 90 kJ/mol is needed to start the degradation process of polypropylene. The autoxidation process begins with the formation of prime radicals ($R^{\cdot}$), followed by a propagation phase with the formation of reaction products (R - OOH), terminated with the formation of inert products.

$$R - H \xrightarrow{\text{sunlight}} R^{\cdot} + H$$
$$R^{\cdot} + O_2 \longrightarrow R - O - O^{\cdot}$$
$$R - O - O^{\cdot} + R - H \longrightarrow R - O - O - H + R^{\cdot}$$
$$R - O - O - H \longrightarrow R - O^{\cdot} + H - O^{\cdot}$$
$$R - O^{\cdot} + R - H \longrightarrow R - O - H + R^{\cdot}$$
$$H - O^{\cdot} + R - H \longrightarrow H_2O + R^{\cdot}$$
$$R^{\cdot} + R - O - O^{\cdot} \longrightarrow R - O - O - R$$
$$2\ R^{\cdot} \longrightarrow R - R$$
$$2\ R - O - O^{\cdot} \longrightarrow R - O - O - R + O_2$$

3. UV RADIATION

Ageing of polymers is caused by the UV section of the light rays. The rate of ageing is determined not only by the intensity of the radiation but also by temperature and humidity. The intensity of the radiation is expressed as an annual irradiated energy on the surface of the earth. The unit for this is kLy (kiloLangley). 1 kLy is 1 kcal/cm2 irradiated energy. In Fig. 1. we see the annual energy distribution in kLy on the earth. In Northern and Middle Europe there is an annual energy incident of 60 - 80 kLy (i.e. 60 - 80 kcal/cm2/year). In Singapore e.g. the energy incident is approximately 140 kLy. This means that it is very important to know in what area of the world the material will be used.

4. STABILIZATION SYSTEMS

To prevent autoxidation, stabilizers are added.
These stabilizers differ in UV absorbing types, quenching types and radical scavengers. UV absorbers are substances which absorb light energy in the wave length region; harmful to the polymer. The absorption depends on the law of Lambert-Beer, i.e. on thickness.

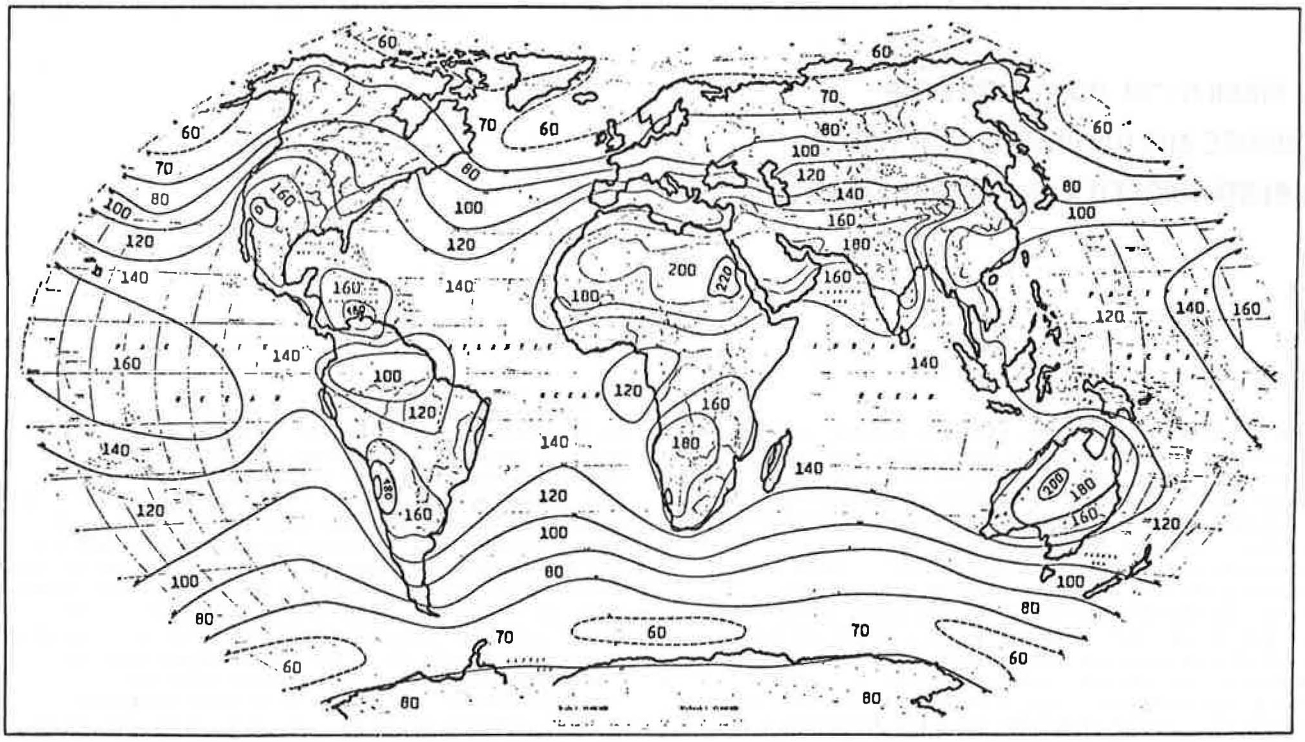

Fig. 1. Generalized isolines of global radiation in kLy (kcal/cm2/year) - After M.G. Landsberg.

Quenchers are complexes or salts of transition materials, such as nickel. Their influence is based on their ability to deactivate photoexcited states and thus preventing degradation. Sterically hindered amines are effective due to their ability to scavenge radicals. Many stabilization systems are combinations of the above mentioned types, which then often exhibit synergistic interactions.
With current stabilization systems the stability of polypropylene is increased to a very high degree.

5. <u>NATURAL AND ARTIFICIAL WEATHERING</u>

One way to obtain information about life expectancy is by outdoor exposure and observing reaction of the material, another is to do an accelerated weathering test.

The results of natural weathering depend upon:
- geographical latitude
- position of sun changing with time of day and year
- local climatic conditions, such as cloud cover and air pollution
- time of year the test is started
- way of exposure of test specimen.

Similarly the results of artificial weathering tests depend upon:
- testing device
- light source and filtering system
- test conditions, such as temperature and rain cycle.

With current stabilization systems the testing of polymers under natural conditions often takes years. Therefore, testing devices have been developed to simulate weathering under accelerated conditions.
Their light source should reproduce the natural spectrum of the sun, particularly in the UV region which is the important one in the ageing of plastics.

Fluorescent black light, fluorescent sun lamp, carbon arc and xenon arc have been light sources used in accelerated weathering devices.
They all have different light spectra. Carbon arcs are still very common. They show a considerable amount of energy below 290 nm, which is the limit for sun radiation on earth. The different light spectra demonstrate the difficulty to compare results of different testing devices. Reactions may be started with one light source which would not have taken place with another.
Nowadays, Xenon burners are the nearest to reproduce the natural sun spectrum.

The American "Atlas Company" and the German "Quarzlampengesellschaft Original Hanau" produce weathering devices with Xenon burners as light source. Carried out under same test conditions, comparable results can be expected from the Weatherometer Xenon arc type (Atlas) and the Xenotest 1200 (Original Hanau). Not only the testing devices, but also the test conditions strongly influence the ageing behaviour. As yet, there is no generally agreed standard. Therefore the influence of test conditions should be demonstrated as an example.

Unless otherwise specified the German standard DIN 53 387 recommends:
- black panel temperature 45° C
- relative humidity during dry period 60 - 80 %
- rain cycle 3 min. rain / 17 min. dry.

ASTM G 26-70, an American standard recommends:
- black panel temperature (63 ± 3)° C
- relative humidity (20 ± 5) %
- rain cycle 18 min. rain / 102 min. dry.

In comparison to the German standard, humidity is lower and temperature about 20° C higher. The risk of having the stabilizers washed-out is minimized due to the lesser amount of rain.

The higher temperature however, increases the degradation rate. In general, chemical reactions are accelerated by increased temperature so that the degradation of polypropylene also accelerates alongside the increasing temperature. As a general rule it can be said that an increase of temperature of about 10° C doubles the reaction rate. An increase of 20° C would mean a four times faster reaction rate.
All these explanations display the difficulties of artificial and natural weathering. Neither test method allows generalizations to be made, i.e. test results depend upon the sample material since the natural environment varies from place to place and from year to year, the effects of natural exposure will vary accordingly. When comparing artificial weathering results, variations might be expected among instruments of different types or when operating similar instruments with different testing conditions.
In addition, the transfer of results of artificial weathering to life expectancy under natural conditions is very difficult. A thorough examination of the test conditions and the natural environment must be made before any conclusions can be drawn.
As one indication the energy incident on the sample after natural and artificial exposure can be taken.
It must however, always be remembered that the same amount of energy in a testing device and of natural weather conditions need not have the same effects on the exposed materials.
Before the transfer of artificial weathering results to life-time measured under outdoor conditions is made, the interpretation of a weathering test should be explained (Fig. 2.).

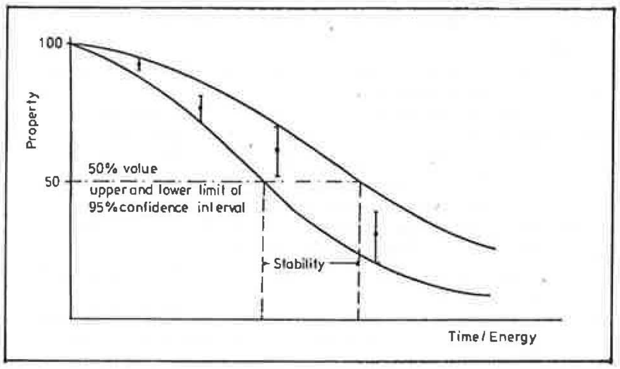

Fig. 2. Interpretation of degradation process.

The materials are exposed to artificial or natural weathering. In order to assess degradation, specimens should be observed at specific intervals and the remaining strength or any other property critical in end use must be measured.
This value is drawn against exposure time or energy.
As no material is totally homogeneous, varying results are obtained after the exposure time. Therefore, never one single curve, but rather a broad band is got for the degradation process. To measure stability, the half life-time, i.e. the time needed for 50 % degradation of the property of interest, is determined. Half life-time can only be expected within certain limits.

6. FIELD EXAMPLE

Two geotextile fabrics of same construction but with different stabilization were examined on UV stability by an artificial weathering test and by exposure to outdoor.

The artificial weathering tests were carried out under the following conditions:

- testing device	: Xenotest 1200
- black panel temperature	: 63° C
- rain cycle	: 18 min. rain / 102 min. dry
- humidity	: uncontrolled
- course	: intermittent course
- test interval	: every 500 h testing of 3 specimen on tensile strength.

When the accelerated UV test is carried out under these conditions then 1 kLy energy incident equals 15 h exposure in the Xenotest 1200.

Outdoor exposure was made in Singapore, a place with tropical climate and an annual energy incident of approximately 140 - 150 kLy. The tests were carried out in the years 1984 and 1985.
The specimens were tightened on a steel frame with a slope of 45° to the South. In periods of three months samples were taken and the loss of strength determined on five specimens.

In the accelerated weathering test Fabric I displayed a half life-time of 2300 h corresponding to an energy incident of 140 kLy (Fig. 3.). Fabric II had 50 % residual strength after 4000 h of exposure corresponding to 240 kLy (Fig. 4.).
Fabric I had a loss of 50 % strength after about 11 months of exposure in Singapore; Fabric II after about 16 months (Fig. 5 and 6.). In literature an annual energy incident of about 140- 150 kLy is given for Singapore; as Singapore has a tropical climate with high temperatures energy incident is taken as the measure for transfer of artificial to natural weathering. The results for Fabric I are in quite good correlation whereas for Fabric II about 20 months of outdoor exposure would be expected; real life-time was about 16 months.

7. PRACTICAL USE OF ACCELERATED TESTS

In practice it will take a long time to determine the UV stability of a polypropylene fabric. In most cases there is no time to carry out outdoor exposure tests of fabrics to be used in a project. The time available between the awarding of a contract and the actual execution of the work is normally only a few weeks to a few months. This means that whenever there is a requirement on the UV life-time of a geotextile accelerated tests are very useful and can give quick easy comparable data.
It is however necessary that whatever test is executed there must exist reliable data to extrapolate the artificial UV test results to outdoor exposure of the same fabric. Amoco Fabrics have obtained a large number of data from tests according to ASTM G 26-70 executed as mentioned in paragraph 6. On the basis of these test results extrapolation can be done to outdoor exposure of fabrics. However, always must be taken into account that temperature will have a negative influence on e.g. the UV life-time. Therefore exact extrapolated data with sufficient reliability cannot be given. Therefore always a sufficient margin in the extrapolated values has to be taken into account.
Another great advantage is that when all fabrics offered on a job are tested according to the same test method it is very easy to compare them. It may well be that sometimes with equivalent fabrics the better UV stabilized fabric can be chosen. However, then the data must be available in a comparable way.

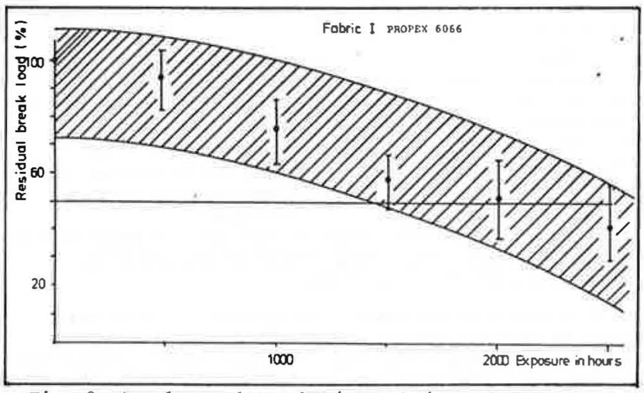

Fig. 3. Accelerated weathering Fabric I.

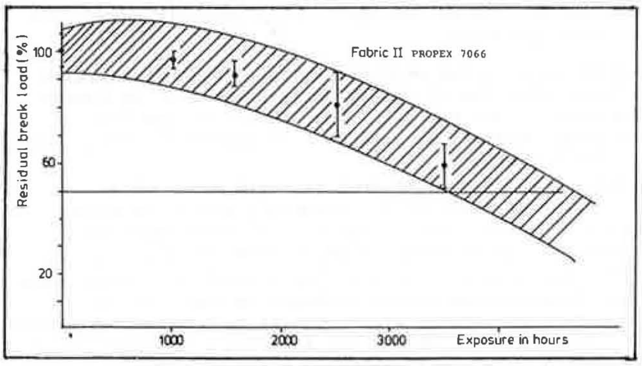

Fig. 4. Accelerated weathering Fabric II.

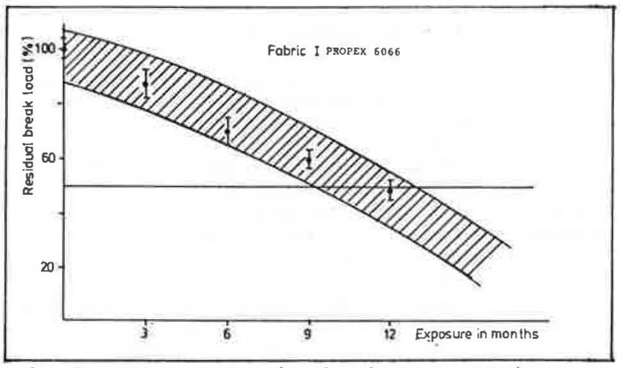

Fig. 5. Outdoor weathering in Singapore Fabric I.

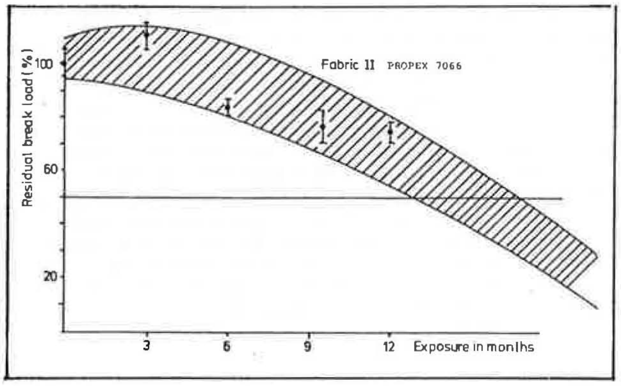

Fig. 6. Outdoor weathering in Singapore Fabric II.

8. EXAMPLES

8.1. Bank Protection Works in Nigeria

For an erosion and flood protection work in Nigeria 18 km of bank protection had to be realised in the lower Niger delta. This project required approximately 1,1 mio m2 of bank protection. It was chosen to protect the embankments with the ProFix mattresses, which are sand filled mattresses produced from polypropylene fabrics. Two layers of fabrics are sewn together in such a way that tubes are formed. These tubes are filled at site with local available sand. The top layer of the fabric was unprotected against UV radiation. For this top layer a heavy polypropylene fabric was chosen with a highly UV stabilized nonwoven needle punched on to it.
For this project it was envisaged that after a certain period vegetation would develop on the mattress which would give it its ultimate UV protection. Now after four years we can see that vegetation has rapidly developed and there are still no signs that the top fabric will cause any reason for concern.
If we look at Fig. 1. we see that the annual irradiated energy is approximately 140 kLy. This means that after four years the total irradiated energy is 560 kLy.
If we would have used the same fabric in Mid-European conditions then the same result would have been realised after approximately eight years exposure (e.g. in the U.K.).

8.2. Design Example

The main questions we have to answer if we plan to use a geotextile in a certain project are:
- How long the fabric will be fully exposed to sunlight?
- What is the annual irradiated energy in the country the project is planned?
- What are the minimum properties required during the life-time of the fabric or what is the minimum required strength during installation and during the life-time of the construction?
- Any additional safety needed to cope for exposure during the life-time of the construction. Possibly top layers can be damaged which can result in a certain time of exposure of the fabric before repair will take place.

If we have answers to these questions we can formulate the specifications of the fabric with respect to the required UV stability.

8.3. Example

Project : Embankment protection
Country : Singapore
Energy incident : 140 kLy/year (Fig. 1.)
Exposure to UV radiation : Max. 6 months
Required minimum strength during installation:
2000 N/5 cm (according to DIN 53 857).

8.4. Solution

Six months exposure in Singapore means a total irradiated energy of 70 kLy. When tested according to the test method as described in paragraph 5 (ASTM G 26-70) this means that 70 kLy $\triangleq$ 1100 h in Xenotest 1200 (see also paragraph 6).
To take into account a certain spread in these figures we could round off to 1500 h.

The requirements of the fabric can be specified then as follows. Minimum required tensile strength 2000 N/5 cm (DIN 53 857) after 1500 h in Xenotest 1200 when tested according to ASTM G 26-70 under the following conditions:

- black panel temperature : 63° C
- rain cycle : 18 min. rain / 102 min. dry
- humidity : uncontrolled
- course : intermittent course.