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The Long-Term Thermo-Oxidative Stability of Polypropylene Geotextiles in the Oosterschelde Project

La stabilité thermo-oxydative à longue durée de géotextiles de polypropylène dans le project de l'Oosterschelde

$4.5x10^6$ m^2 block-mattress will be used for bed protection around the storm surge barrier in the Oosterschelde. The durability requirements for the polypropylene (PP)-bottom fabric in this mattress have been set extremely high (200 years). In pursuing these requirements, several improved antioxidant systems have been tested. These tests show that a high stability level combined with a high leaching resistance are the two prerequisites for antioxidant systems in the PP in order for it to be appropriate. Long-term tensile strength experiments have shown, that under practical circumstances the thermo-oxidative resistance of the material is the overruling, determining factor for the technical life of the PP-fabric.Non-woven spunbonded PP-sheet has been subjected to heat-ageing test at 50°-140°C, in its original state and in extracted state. On the basis of these results estimates have been made on technical life in bed protection (10^3 years). A geotextile has been selected for the gravel bag in the storm surge barrier on the basis of its weatherability.

Un matelas de blocs en beton de $4.5x10^6$ m^2 sera employé pour protection de sol autour du barrage anti-tempête dans l'Oosterschelde. Les exigences de durabilité au tissu de fond de polypropylène (PP) dans ce matelas ont été placées extrêmement hautes (200 ans). A la poursuite de ces exigences, plusieurs systèmes d'anti-oxydants améliorés ont été éprouvés. Ces épreuves montrent qu'un haut niveau de stabilité, combiné avec une haute résistance au lessivage, sont les deux choses nécessaires auparavent pour des systèmes anti-oxydants dans le PP afin qu'il soit approprié. Expériences de résistance à la traction à longue durée ont montré que, dans des circonstances pratiques, la résistance thermo-oxydative de la matière est le facteur dominant et déterminant pour la vie technique du tissu PP. Du membrane de PP non-tissu a été soumis à des expériences de vieillissement à chaud à 50°-140°C, dans son état original et dans un état d'extraction. A la base de ces résultats évaluations ont été faites de vie technique de protection de sol (10^3 ans). Un géotextile a été sélectionné pour le bourrelet de gravier au barrage anti-tempête.

1. INTRODUCTION

During the development and execution of the Delta Works in the Netherlands, a rapid evaluation of bed protection methods has taken place (1). The necessity of protecting very large areas of the sea bottom together with an increasing scarcity of willow led to the development of synthetic fabrics for use as a base for prefabricated bottom protection constructions. In 1973 the so-called block-mattress was developed, being one of the trendsetting new types of bed protection.Because of soil characteristics the sand-impermeability of the block-mattress had to be improved; this was achieved by using a non-woven spunbonded polypropylene sheet on top of the PP-bottom fabric. In about the same period the so-called fixtone-mattress was developed. The aim of the work reported in this article has been to get a better insight into what factors determine the durability of the polypropylene geotextiles used in the bed protection units mentioned above. Requirements and generally practicable test methods had to be formulated, against the background of the Oosterschelde works. It appears, that once these mats are placed and in most cases covered by slag, gravel, quarry stone and/or asphalt mastic, the main risk for a proper long-term functioning is the possibility that the material will be unable to resist oxidative degradation. In addition the PP-fabric of the block-mattress should retain a minimum long-term mechanical strength under load because of the possibility of sudden soil displacements, leaving parts of the mat in a hanging, loadbearing position. Evaluation and testing of the various possible stabilizer systems form the subject of the present paper. For this purpose heat aging tests combined with leaching tests were used. These leaching tests were carried out over varying periods; this pre-treatment of test specimens will also be indicated by the term "extraction". In order to check the influence of mechanical load during thermo-oxidative degradation long-term mechanical strength experiments have been carried out at elevated temperature. As a representative of PP-fibres in various thicknesses, a non-woven spunbonded polypropylene sheet was selected for a more detailed programme of oven aging tests. Tests were carried out on the original as well as on the (sea water) extracted state, in order to establish a relationship between time to failure in heat ageing versus temperature. In addition, the relationship between time to failure in heat ageing and time of extraction at a moderately elevated temperature was also investigated. Polyamide fabric used for a gravel bag around the foot of the piers of the storm surge barrier in the Oosterschelde has been tested for weather-resistance over a limited period.

2. EXPERIMENTAL PROCEDURE

2.1. Oven-ageing tests

These tests have been executed in Heraeus Type T 5060 EK ovens,which have a cubic space($600x600x600mm^3$). Forced air circulation was not used. Air circulation velocity drastically influences the oven-ageing time to failure ("ovenlife"); when forced circulation is used, a substantially shorter ovenlife is observed than in the case of natural convective circulation (2). Therefore, in most standard tests forced air circulation is prescribed (3), also because then requirements related to temperature tolerances can be met more easily. A permanent difficulty in these tests, however, is the variation in air circulation velocity which occurs throughout the oven space, leading to a scatter in results. If a natural draught is applied, air circulation in ovens of this size adjusts itself in an experimentally reproducible way. According to our experience, even ovens of different design (namely arrangement of air outlets, etc.) can apparently be operated under practically equivalent conditions, and can consequently give equivalent results, provided that only a central part of the oven space is used. Tests were executed in a temperature range of 50° - 150°C, the temperature variation being not more than ± 0.5°C. Under these conditions the fresh air replacement ratio per hour is about 7 - 9 times the volume content. Test specimens (yarns 100 mm long, filters 40 x 150 mm^2) were suspended from glass clips in the centre of the oven, at a distance apart of 40 mm. In the case of the experiments on non-woven spunbonded PP-sheet test pieces were hung on a carrousel, which could be turned by hand around the vertical axis. At regular time intervals the test specimens were checked for embrittlement and the carrousel was turned by hand through 90°. In some cases premature embrittlement was observed due to gaseous dissociation products, originating from PP-residues on the hot oven bottom, which apparently catalysed the thermo-oxidative breakdown (4). This contact with the bottom was eliminated by using detachable aluminium foil trays covering the oven bottom and collecting the fallen residues, which could then quickly be removed during the daily check. The tests were terminated when the first of at least 20 specimens had become brittle.

2.2. Leaching tests

Leaching of test specimens in sea water, sampled from the Oosterschelde, was done in a 31 round bottomed flask, filled with sea water up to 2/3 of its volume. Test specimens were put into the flask, and completely immersed. A reflux cooler was connected to the flask and its content heated and refluxed for a fixed period. Afterwards the specimens were rinsed with cold water and dried in the air.

2.3. Long-term tensile strength tests

Tensile tests under constant load were done at 90° and 110°C. Two types of yarn were tested and coded A and B. From the yarns circular test specimens were made, total length 200 mm, the circle being closed with a suitable knot. The knotted specimens were suspended on the fixed upper connecting device of an Instron dynanometer drawing bench, in principle consisting of two metal pins, diameter 4.5mm, 13.5mm apart. Using a similar device connected to the moving traverse of the drawing bench the test specimens could be loaded and tested in tension. The raised temperatures were achieved by using an Instron dynanometer high temperature cabinet. Firstly, the reference breaking force F_T was determined.The traverse speed of testing was 50 mm/min. After that, a series of set percentages of this breaking force was applied as a constant load F and the time to failure was recorded. Tests with the lower loads ($<0.3F_T$) were executed in thermostat controlled oven cabinets with automatic time-to-failure recordings.

2.4. Artificial weathering test

In order to choose between two synthetic fabrics for use in the manufacture of gravel-filled bags around the foot of the piers of the storm surge barrier in the Oosterschelde (5) it was necessary to know the weatherability of the fabrics over a limited period (1.5 years). Test specimens, 50x250mm^2, were taken from the fabrics, and subjected to an artificially UV-ageing treatment in a Xenotest 1200 U accelerated weathering apparatus (Original Hanau Quarzlampen GmbH, Hanau, Western Germany). The test conditions were:

internal test chamber temperature : 25°C
black panel temperature : 47°C
filtering: 2 (instead of 3) "UV-Drittelschalen"
Artificial rain: 3 minutes/20 minutes running time
relative humidity: 60%
intermittent irradiation: 50/50

The light sources were 3 Xenonlamps, each 4500 W, situated in a selective (UV-reflecting, IR-absorbing) mirror system, surrounded by a quartz, water-filled cylinder. Around this cylinder the 3 "Drittelschale"-filters fit in their mountings. After the UV-ageing treatment, the specimens were subjected to a tensile test (distance between grips 140mm, speed of testing 100mm/ min., 23°C/50% R.H.). The breaking force, F_T, was determined, and compared with the corresponding findings for the unaged samples. As a basic requirement it was decided, that a reduction in strength larger than 20% would be unacceptable.

3. TEST RESULTS AND EVALUATION

3.1. General purpose polypropylene filter fabrics

For some 10-20 years polypropylene fabrics have been used in bed protection and embankment reinforcing units. Polypropylene can be considered as almost completely resistant to biological and chemical attack in sea water, and is therefore preferable to wooden or willow materials. For the Oosterschelde works, PP-fabrics for the block-mattress were initially woven out of yarns produced from fibre grade polypropylene homopolymer, containing 0.5-1.5% carbon black, about 15% (weft) to 20% (warp) polyethylene, and a rather moderate amount of antioxidants. These yarns were obtained by foil extrusion and water-bath chilling, then cutting in strips of a defined width, hot drawing, fibrillation, twisting (for warp) and winding. Water-permeability and sand-impermeability characteristics were produced by a special weaving technique. The required strength for the sinking operation was produced by optimising the drawing ratio and the linear mass of the yarns. However, how the strength of the yarns would change on the long term was unknown. This is of considerable importance since, under unfavourable conditions, the block-mattress, lying on the sea bottom,might still be loaded up to 10% of its strength (see Section 3.3). In this connection, the oxidation stability level must be sufficiently high throughout the technical lifetime. The general purpose PP-fabrics mentioned above generally showed an average ovenlife of 3 days at 150°C (6 days at 140°C). However, extraction with either sea water or a 2% Teepol GD 53 P solution at 100°C caused a reduction of the ovenlife to 30%. Some typical values are given in Table 1. These tests were carried out on a large number of samples (also on fixtone mattress fabric) with essentially the same results. Deviations in results were not more than 1 day. Warp and weft were also analysed with respect to the antioxidant content, the results being summarized in Table 2.

Table 1. Ovenlife (days) at 140°C, block mattress PP-fabric, warp and weft; before and after extraction in Teepol solution and seewater at 100°C.

	fabric	warp	weft
. unextracted	6	6	6
. extracted in Teepol			
solution - 7 days	2	2	2
- 14 days	2	2	2
. extracted in sea			
water - 14 days	2	2	2
- 28 days	2	2	2

Table 2. Weight percentage antioxidant* in warp en weft of the block-mattress fabric before and after extraction in sea water at 100 °C.

	warp		weft	
	Ionol	Irganox 1010	Ionol	Irganox 1010
. unextracted	.043 (±.002)	.0102 (±.0004)	.072 (±.004)	.0134 (±.0004)
. extracted, 8 weeks	<.001	.002	<.001	.004

* Ionol : 2,6-di-tert.-butyl 4-methylphenol
Irganox 1010 : penta erythrityl-tetrakis-[3-(3,5-di-tert.-butyl-4-hydroxy-fenyl)-propionate]

From these results it was concluded, that long-term leaching of protecting antioxidants had to be taken into account. Essentially the same conclusions were drawn from other studies, where similar fabrics, used in bed protections in the Delta Works for several years and dredged from the sea bottom, were analysed and compared with original material. In the planning of the storm surge barrier it was decided, that every prefabricated element, which in principle could not be replaced, should have an expected life of at least 200 years (1). On the basis of considerations which will be dealt with in Section 3.4, a residual ovenlife of 2 days at 140°C was then considered to be insufficiently compatible with this requirement. Furthermore, the revised concept of the storm surge barrier required an increase in the total area of sea bottom to be covered with block-mattresses from $1.5x10^6$ m^2 to $4.5x10^6$ m^2, reaching as far as 600m from the barrier axis on both sides. In this concept the bed protection will be exposed to tidal currents. This requirement therefore has constituted another reason for improvement of the antioxidants with respect to leaching.

3.2. Low-leach polypropylene filter fabrics

At the request of Rijkswaterstaat, a first low-leach stabilizer formulation, to be applied as a master batch, designated as PLZ 453, was evaluated by Shell Nederland Chemie. Ovenlife tests were done on 0.5mm sheet test specimens at 150°C instead of 140°C, giving the results summarized in Table 3.

The samples which were sea water extracted for 56 days were also analysed for antioxidants (Table 4).

Since these results indicated a substantial increase in leach resistance and thermo-oxidative resistance this system was introduced in split film fibre production, and the yarns produced (film thickness 60-70µm) were again tested (Table 5).

From these results it can be seen that, in comparison with the results for the 0.5mm sheet, the initial ovenlives are less, mainly due to the difference in thickness and the influence of processing and twisting. In this respect the difference between warp (fibrillated and twisted) and weft (flat tape yarn) is systematic, the warp value being the lower value. Also, the leaching effect is more pronounced, especially for the warp yarn. This stabilizing system, originally applicable for low-leach injection moulded parts,appeared to cause difficulties in foil extrusion. After the water-quenching step the foil showed water carry-over, which spoiled the stretching conditions. Therefore, another stabilizing system was formulated where Irganox 1010 and DMTDP were replaced by Ionox 330*, which is insoluble in water and does not show the disadvantages in processing mentioned above. The warp yarns produced were tested for thermo-oxidative resistance and leaching resistance, leading to the results given in Table 6. Experiments were done in two separate ovens of different design.

Table 3. Ovenlife (days) at 150°C,of PLZ 453 stabilized PP-sheet 0.5mm, before and after extraction at 100°C.

. unextracted	20
(. unextracted general purpose	3)
. Teepol extraction	
- 7 days	13
- 14 days	11
. Sea water extraction	
- 14 days	17
- 28 days	15
- 56 days	15

Table 4. Weight percentage antioxidant* in PLZ 453 stabilized PP-sheet, thickness 0.5 mm, before and after extraction at 100°C.

	Irganox 1010	DMTDP	Ionol
. unextracted	0.118 (±0.003)	0.35 (±0.01)	0.05
. extracted in sea water, 56 days	0.094	0.23	0.002

* DMTDP = di-myristyl-thio-di-proprionate

Table 5. Ovenlife (days) at 150°C of PLZ 453 stabilized block-mattress yarns, before and after extraction at 100°C.

	warp	weft
. unextracted	9	12
. extracted in sea water		
- 7 days	6	10
- 14 days	2	8

Table 6. Ovenlife (days) at 150°C of improved PLZ 453 stabilized block-mattress warp yarns, before and after extraction at 100°C.

	Oven A	Oven B
. unextracted	15	16
. extracted in sea water,		
- 1 week	10	11
- 2 weeks	4	4

* Ionox 330 : 1,3,5-trimethyl-2,4,6-tris-(3,5-ditert. butyl-4-hydroxy-benzyl)-benzene

Although an improvement in oxidative stability was again achieved, the additive system was accompanied by a lower production speed, so that Shell Nederland Chemie decided to develop another low-leach stabilizing system, this time especially intended for extrusion processing of these fibres. This system was called PLZ 458, the components of which were not disclosed. The warp yarns produced were tested as before, giving the following results (Table 7).

It was concluded that the PLZ 458 system could be considered as equivalent to PLZ 453, if not being better. It was recognised furthermore, that within one production stream a certain scattering in ovenlife can occur due to imperfections in dispersion of the antioxidant masterbatch over the bulk polymer. This illustrates the

Table 7. Ovenlife (days) at 150°C of PLZ 458 stabilized block-mattress warp and weft yarns before and after extraction at 100°C.

	Sample I warp	Sample I weft	Sample II warp	Sample II weft	Sample III warp	Sample III weft
. unextracted	15	17	13	20	19	18
. extracted in sea water						
- 1 week	10	13	5	13	10	16
- 2 weeks	10	13	4	12	8	14

Table 8. Ovenlife (days) at 150°C of two warp yarn samples PLZ 453 stabilized, before and after extraction at 100°C.

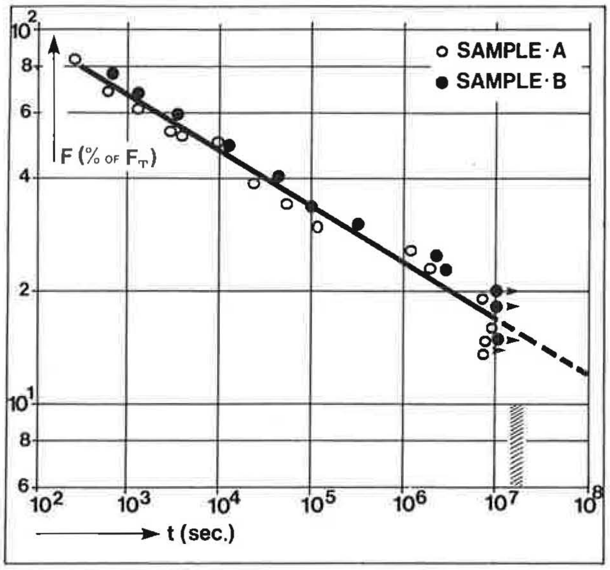
	Sample A	Sample B
. unextracted	11	14
. extracted in sea water		
- 7 days	9	11
- 14 days	8	11

necessity of maintaining an efficient production control.

3.3. Long-term tensile strength of PP-split film yarns

Because of the possibility of sudden soil displacements, leaving parts of a block-mattress in a suspended, load-bearing position, it was necessary to investigate the long-term strength of the PP-yarns. Two warp yarn qualities (PLZ 453 stabilized) coded A and B were investigated. The ovenlife and extraction resistance were also tested (Table 8).
Long-term tensile strength tests were done at 90°C and 110°C, from which the results at 110°C are shown in Figure 1. Experimental details are given in Section 2.3.
There is hardly any difference between sample A and B. The same conclusion can be drawn from the results at

Fig. 1 Time to mechanical failure of two samples polypropylene splitfilm yarns (1900 tex) under constant load at 110°C. The shaded area represents the time interval where the ovenlife of the yarns may be expected.



90°C. An ovenlife at 110°C can be estimated from the ovenlife at 150°C (11 and 14 days), yielding a value $\sim 2.10^7$ sec. (230 days). This estimate, made on the basis of ovenlife experiments and assumptions given in Section 3.4, has been incorporated in Figure 1 as a shaded area. From construction calculations it is known that under the most unfavourable circumstances the load remaining on the block-mattress after sinking add up to a maximum of 10% of the breaking strength. From Figure 1 it can be seen that for loads up to 0.1 F_T the extrapolated time of failure ($>10^8$ sec) would become longer than the time needed for (unloaded) thermo-oxidative breakdown. Therefore, at this load-level it is the thermo-oxidative resistance of the polypropylene which constitutes the determining factor in the functioning of the PP-fabric. Tests were terminated at 10^7 sec (116 days). At that time there were no signs of embrittlement.

3.4. Non-woven spunbonded polypropylene sheet

In order to establish an estimate of the durability on the basis of the ovenlife tests the relationship between ovenlife, t_o, and temperature should be known. This relationship is commonly represented by the formula

$$t_o = A.e^{\Delta H/RT}$$

where A = a constant
ΔH = activation energy
R = gas constant
T = absolute temperature

At higher temperatures (>80°C) activation energies for PP are reported in literature, to range from 80-110 kJ/mol. As a consequence, ovenlife tests at lower temperatures than 150°C or 140°C are increasingly time consuming. Experiments on the high-stability low-leach formulations, discussed in Section 3.2, would therefore be hardly feasible. In order to avoid these well-known difficulties as much as possible, the non-woven spunbonded PP-sheet, used in the block-mattress, was chosen for a more elaborate experimental program. The stability level was lower than the block-mattress PP-fabric; moreover, tests on sea water extracted and also on diethylether extracted (= unstabilized) sheet could be done, which presumably would not take a too long time. The mass per unit area of the sheet was $170 g/m^2$, the thickness was ca 0.4mm, the diameter of the primary filament being ca 15 μm. The material was analysed for antioxidants, and appeared to contain:
0.004 w/w % Ionol
0.062 w/w % Topanol CA: tris (2-methyl 4-hydroxy 5-tert. butyl-phenyl)butane
0.370 w/w % Cyasorb UV 531: 2-hydroxy 4-n-octyloxy-benzophenone
0.06 w/w % carbon black
Ovenlife tests were done at temperatures ranging from 50°-140°C, each experiment being on 12 test pieces. A logarithmic time-average ovenlife was calculated, together with a logarithmic standard deviation interval for observed values (Table 9).
These results are shown in Figure 2; they clearly show that the relationship is not-linear but turns of slightly towards shorter ovenlife times at lower temperatures. This effect is found generally (6) and is attributed to the varying effectiveness of the stabilizing system, depending on diffusion and solubility in the polymer, being governed by temperature. For this reason ΔH varies with T. For temperatures above 80°C we found a ΔH-value of 93kJ/mol (unstabilized PP), which is in fair agreement with literature. Because of the experimental inaccessibility, literature data on ΔH-values at lower temperatures are scarce. Below 80°C ΔH tends to decrease gradually. For unstabilized natural PP, values of about 50 kJ/mol are reported (7). Our results indicate a value below 70°C of about 65 kJ/mol,

Table 9. Ovenlife (days) of non-woven spunbonded PP-sheet at different temperatures; logarithmic time averages and (s.d. interval).

Temperature (°C)	Unextracted	Extracted in sea water - 7 days, 100°C	Extracted in diethylether
140	13.8 (12-16)	4.1 (3.0-6.0)	< 1 (-)
120	61.6 (53-71)	20.5 (13-32)	1.1 (0.9-1.5)
100	160.7 (151-171)	57.6 (49 - 67)	6 (-)
80	456 (430-480)	237 (225-249)	31.4 (30-33)
70	-	-	83 (-)
60	-	> 300	168 (158-178)
50	-	-	> 300

Table 10. Ovenlife (days) at 120°C of non-woven PP-sheet vs time of extraction (days) in sea water, 50°C; logarithmic averages and (s.d. interval).

time of extraction	0	35	70	175	350
ovenlife	61.6 (53-71)	33.5 (32-35)	29.0 (28-30)	19.0 (15.5-23)	4.4 (2-9)

giving a reasonable agreement, since, in the extracted sheet the low content carbon black may have increased the activation energy. The graph of the extracted sheet appears to be about a factor of 10 lower than the unextracted sheet, whereas, as could be expected, the sea water extracted sheet lies in between. The average temperature of the sea water in the Oosterschelde is about 5°C. If one should calculate for the extracted sheet an induction time for embrittlement at 5°C from the 60°C-value, using as activation energies 50 and 65 kJ/mol (as a low and a high estimate), this would yield 16 and 48 years, in air respectively. Since the oxygen content in the water is about 1/7 of the oxygen content in air, the time to embrittlement in water will be accordingly longer. The relationship between oxygen intake and oxygen pressure (a hyperbolic function) is not known exactly. However, from analogous experiments it may be inferred(8) that a factor 4 is fairly realistic, bringing the expected technical lifetime of the extracted sheet to 65-190 years. As a best guess, we assume that the graphs for the extracted and unextracted sheets will run essentially parallel to each other. Since ovenlife values of the unextracted material are about a factor of 10 higher, this leads to a calculated life of 6.5×10^2 - 1.9×10^3 years. Hence, the non-woven sheet can meet the durability requirements, if losses of stabilizer can be restricted. To get an impression regarding this phenomenon and, at the same time, to evaluate the meaning of the 7 days 100°C-extraction, a long-term extraction at 50°C was carried out. To quantify the effect of extraction, ovenlife values at 120°C were determined (Table 10, Fig. 3).

It can be concluded that extraction at 100°C over 7 days - which produces a reduction in ovenlife to 20.5 (Table 9) - gives a fair impression about the extractability, since the effect is the largest in the initial stage. Apparently a judgement about extractability of stabilizing systems does not necessarily involve long extraction times. Furthermore it can be seen, that after quick initial extraction of stabilizer this process slows down considerably. This is also a feature which was observed at the selected PLZ 458 stabilized PP-yarns (Table 7), where a more or less constant ovenlife level was reached at prolonged extraction. Comparison of the same figures with values in Figure 2 shows, that the corresponding points (which are minimum values and not average values) and graphs of the PP-yarns lie above the not extracted PP-sheet graph. If the above mentioned approximations regarding ΔH also hold true for the PP-yarns, a residual ovenlife level after long-term extraction, say 10 days at 150°C, would imply a 1.5 times higher stability than the unextracted non-woven PP-sheet. This would amount to an expected minimum lifetime of about 10^3 years. The large uncertainty regarding ΔH-values in the low temperature region cannot be denied. On the other hand, this calculation is generally conservative. Therefore it is likely that, within the boundaries of existing knowledge, the durability requirement is met by the PLZ 458 stabilized fabric.

3.5. Polyamide fabric for the gravel-filled bag

When considering the selection of a fabric for the gravel bag (5) a weatherability test was necessary in order to ensure a sufficient UV-resistance of the fabric before immersion in sea water. It was required that the fabric should show a less than 20% reduction in strength in an outdoor exposure period of 1.5 years. Two fabrics were tested as described in Section 2.4, namely

- a fabric, consisting of PP (warp) and linear polyester PETP (weft)
- a fabric, consisting of polyamide (warp and weft).

Fig. 2 Time to mechanical failure of non-woven spunbonded polypropylene sheet, by heat-ageing in an oven, as a function of temperature.

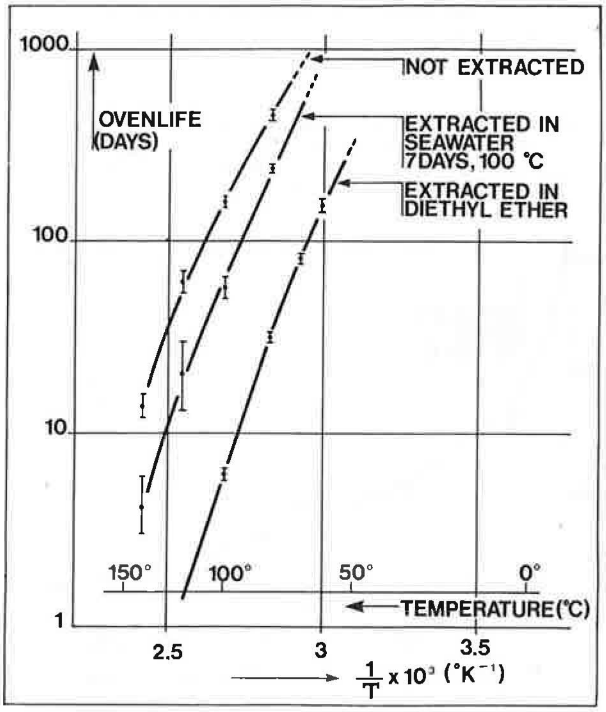


Table 11. Results of the accelerated weathering test.

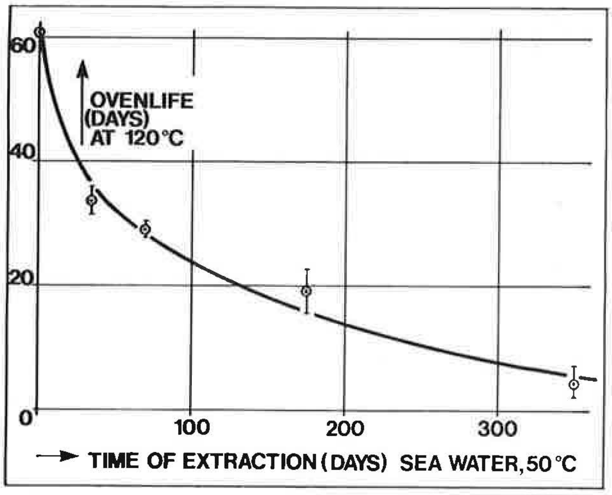
	breaking load (kN)		
ageing time	0 hours	250 hours	500 hours
PP warp	9.7	9.2	8.6
PETP weft	5.9	3.0	2.3
PA fabric	7.9	7.8	7.2

According to our experience, 450 hours accelerated weathering is equivalent to 1.5 years. The reduction in strength regarding PP and PA is acceptable, whereas for PETP the reduction even after only 250 hours was unacceptable. On the basis of this result the PA-fabric was recommended. Suspension loops are sewn on the gravel bag, for tying it up against the pier, during transport and placing of the pier. Therefore, the stitchings of the loops have also been tested for UV-resistance by subjecting a complete sample of gravel bag, with a loop connection in it, to the accelerated UV-test. After this, the test sample was mechanically tested on the Zwick 1484 200 kN tensile tester of the Laboratory for Fibre-Engineering of the Delft University of Technology. The loop was drawn through a 45° angle, increasing the tensile force over a period of 1 minute up to the required initial value of 50 kN. This was done twice, with no effect on the loop. The test was repeated and the applied force was increased up to failure at a maximum force of 56 kN. The ropes were broken whereas the seams remained unimpaired. It was concluded therefore that the gravel bag would be able to resist weathering during the 1.5 years without showing an unacceptable loss in strength.

3.6. Conclusions

The results of the long-term mechanical strength experiments demonstrate, that with regard to the durability of bed protections used in the Oosterschelde project the thermo-oxidative resistance of the PP-woven structure will be the determining factor. It has also been demonstrated that in protecting the PP against thermo-oxidative breakdown in the sea water on a 200 years' term the stabilizing system must have a high stability level combined with a high resistance against leaching by sea water. These two characteristics are the prerequisites for fulfilling the high demands of the Oosterschelde project. It has been shown that this aspect can be effectively controlled by a combination of extraction tests and oven tests. Although there is uncertainty about the appropriate values of ΔH in the lower temperature region, a generally conservative calculation demonstrates that the PLZ 458 stabilised fabric can meet these high durability requirements: the technical life is estimated at 10^3 years.

Fig. 3 Time to mechanical failure of non-woven spunbonded polypropylene sheet by heat-ageing in an oven at 120°C, plotted against the time of preceding extraction in sea water at 50°C.



4. APPLICATIONS OF TESTING METHODS IN CERTIFICATION AND PRODUCTION CONTROL

On the initiative of Rijkswaterstaat Deltadienst, a Working Group "Plastics in Water Works" was formed in 1976, which started to formulate requirements related to PP-yarns for fabrics for block-mattresses as well as fixtone mattresses. These requirements plus test methods were issued as so-called K-sheets (9), and contain requirements regarding linear mass, specific tensile strength and elongation at break, for warp and weft separately. Also a test requirement for the thermo-oxidative resistance of the yarns before and after sea water extraction at 100°C during 7 days was established, being 12 and 6 days minimum ovenlife at 150°C. Experimental conditions were specified in accordance with Section 2.1. In the Netherlands a KOMO-certificate is granted to manufacturers able to deliver yarns meeting these specifications. To achieve this the manufacturer must maintain an internal quality control system which is assessed and controlled by the KIWA Institute, the external executive testing institute of the KOMO Foundation. The internal quality control applies to not only the testing of yarns but also to the complete production process. A detailed list of points to be checked is drawn up by the manufacturer together with the KIWA Institute. Regular checks and samplings are made by KIWA inspectors, who are authorized to enter the factory at any time. It has been our experience, that certification and production control has improved the quality of the components to a considerable extent. Also the evaluation of new stabilizing systems and their incorporation in production has undeniably been stimulated by the certification activities. In the near future the results of these experiments discussed above will be utilized for the formulation of general specifications concerning a limited number of geotextile classes.

5. REFERENCES

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