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Variation in creep rate at constant loading of PET geogrid strapping

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ABSTRACT: Creep tests have been executed on PET strapping material. The measurements were very precise which resulted in the recognition of different creep rate patterns at various loadings. This data allowed to further verify the molecular chain transformation model which has been established for PET yarns. Creep data from other tests were used to validate the model. A simple method has been proposed to calculate the creep during the service life of a PET reinforcing material using elastic strain, strain during the first 1,000 sec. and the constant creep rate in the rest of the service life. This paper gives additional support to the model of creep deformation at molecular level which is developed in our other paper at this conference (Residual strength of PET after more than 12 years creep loading) and which is based on the stress-strain model developed by Van den Heuvel.

1 INTRODUCTION

The creep of polymer material has been investigated by many researchers in the past 25 years. A lot of effort has been put in the transfer of the creep data into design rules. Colbond Geosynthetics has been active in the research on creep on PET material since 1975. Many papers have been published on creep programs which we have executed, at that time under our previous name Akzo Nobel Geosynthetics (Den Hoedt, G., 1986; Viezee D.J. c.s., 1990). This all has let to much better insight in the magnitude of creep and the use of these phenomena in design. Creep ends in rupture and the use of a stress-rupture line for design for certain service lifetime has become a standard design tool (Voskamp W., 1985).

Nowadays it is normal practice to execute prolonged loading tests in accordance with the applicable standards and measure the creep up till 10,000 hrs. The loads are taken at higher levels to allow for rupture during the test period. Preferably the loads have to be at at least 3 different levels to allow a reliable extrapolation of the line drawn through all rupture points: the stress-rupture line. Extrapolation is done over 1 or 2 decades. Because creep testing executed in the conventional way takes a very long time, methods have been developed to speed up the process. First Time Temperature Superposition (TTS) became in use. This method uses the concept that increasing temperatures accelerate the creep rate, thus the time for the creep to develop is reduced. Creep curves are shifted and lead to a master curve which is used for extrapolation. In the last years a new method has been published: Stepped Isothermal Method (SIM) (Thornton, J.S. c.s., 1997). Since 1987 an extensive creep measuring program is being executed at the Colbond Geosynthetics laboratory which has given interesting results. In this paper the results of our creep program on PET straps are published. These very detailed readings gave insight in the variation of creep rates at various levels and showed some surprising results.

2 DESCRIPTION OF THE TEST

Creep tests have been executed at samples taken from our newly developed Enkagrid material. This geogrid consists of continuous straps which are connected to each other by means of a laser welding technique. The production method has been described by W. Voskamp, 2000. The tests were made at samples, one strap wide, creep was measured with an optical device resulting in accuracy in reading of 0,01 mm or 0,033%. The tests were executed in accordance with EN-ISO-13431, sample length between measuring points was approx. 300 mm. Tests were made at load levels of 10, 20, 30, 40, 71, 73 and 75% of the ultimate tensile strength. The higher loadings were selected to give rupture within the testing period. The lower range was used to get detailed creep results. Further Stepped Isothermal Method tests were executed by ERA and published by J. Greenwood, 2000. Based on this program the stress rupture level of 68,5% was established for a service lifetime of 114 years. The tested material has a strength of 104 kN/m at an elongation at break of

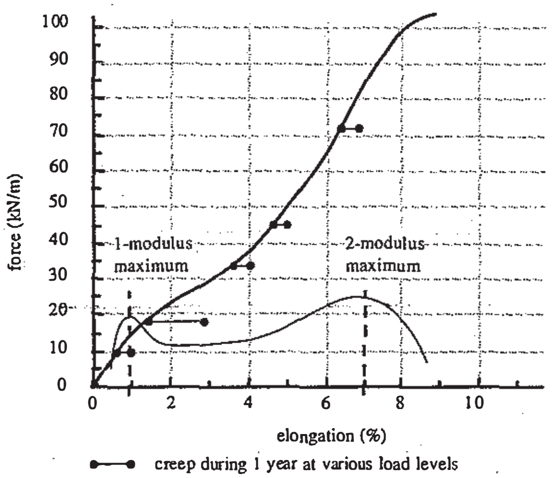


Figure 1. Typical stress-strain curve of type 90.

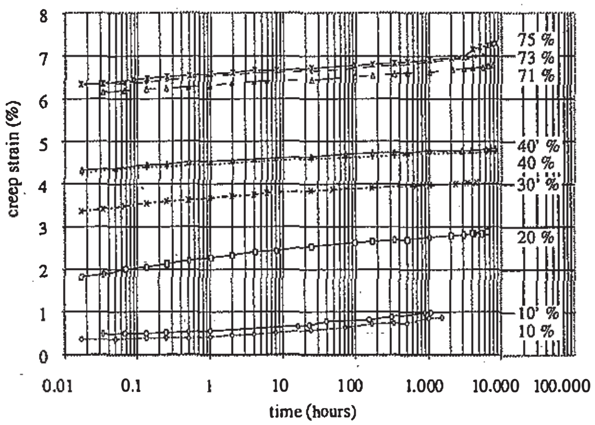


Figure 2. Creep-strain results of type 90.

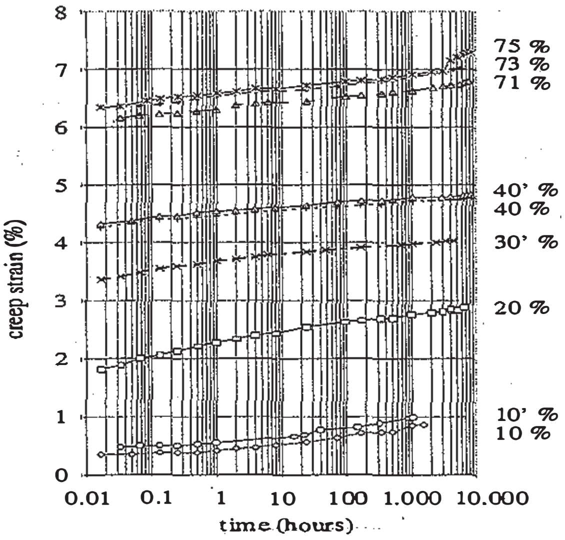


Figure 2. Creep-strain results in compressed scale.

8%. The modulus of this material is considerably steeper than that of PET yarns. The stress-strain curve is given in figure 1.

The modulus of the strap varies at different stress levels, therefore the modulus is also shown in this figure. The creep of the material was measured and is shown in figure 2.

This is the traditional way of presenting the creep results. If we compress the time scale much more we can see differences in the creep lines.

At 10% load level, the strain increases in time as shown by the concave shape of the curve. The levels 20, 30, 40% shown a convex shape. This convex shape, with decreasing strain in time is the normal shape of the creep curve. At the high levels we can see some increase in creep rate which indicates the start of the well known upswing. However, the concave curve at 10% load level was unexpected. This brought us to investigate if this behaviour could be explained by a description of the molecular changes during loading.

3 MOLECULAR CHANGES OF PET YARNS DURING STRETCHING

In our other paper at this conference (W.Voskamp 2001) we have described the changes which take place at molecular level during the loading of PET yarns during stretching. These changes were investigated at Akzo Nobel Research Laboratories by using rheo-optical infra red spectroscopy and other techniques and published in 1993 by Van den Heuvel, C.J.M. It was found that the modulus of the stress-strain curve of PET material varies a lot and has typically 2 maxima. For clearness sake we quote in the following section the description of the molecular changes during loading as we have written in our other paper to this conference. Quote:

Clearly 2 maxima can be found in the modulus curve: one around 0,5 – 1% strain and the other at about 7 - 8% strain.These stress-strain curves can be divided in 3 regions using these maxima. The molecular deformations which take place in these 3 regions are clearly different from each other.

Region 1: up to the first maximum in the modulus (around 0,5 – 1%).

Region 2: between the first and the second maximum in the modulus (between 0,5 – 1% and 7 - 8%)

Region 3: after the second maximum in the modulus.

To understand the processes which take place in the 3 regions it is necessary to look at the physical structure of PET, a two phase model with amorphous and crystalline domains (Den Hoedt, 1986, V.d. Heuvel, 1992).

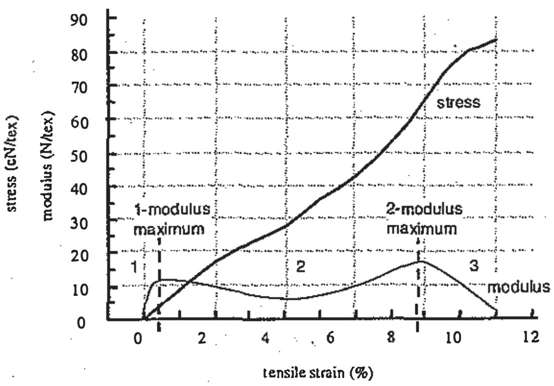


Figure 3. Typical stress-strain curve with modulus (V.d. Heuvel, 1993).

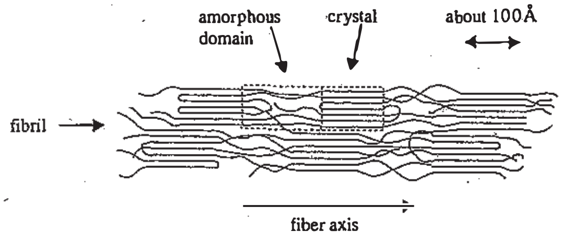


Figure 4. Physical structure of PET yarn (V.d. Heuvel).

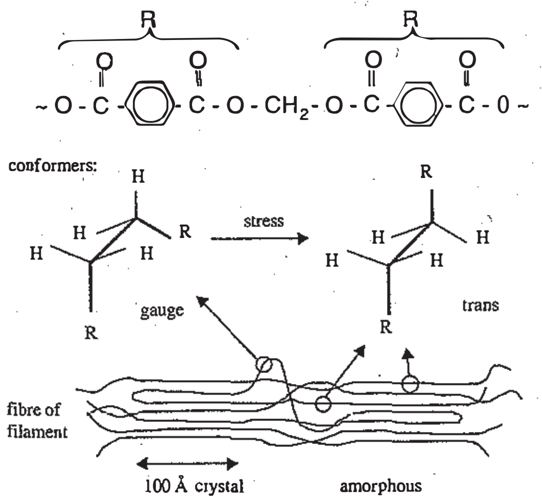


Figure 5. Molecular and physical structure of PET (V.d. Heuvel).

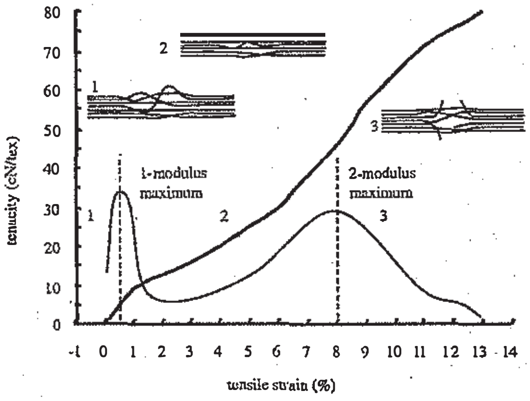


Figure 6. Molecular processes in the 3 regions.

During straining the PET molecules will uncoil. The ethylene groups in the amorphous domains of semi-crystalline PET occur in 2 conformations, gauche and trans conformation. Molecule chains with a lot of gauche will be coiled strongly, trans conformers in series give rise to extended chains. The crystalline zones consist only of trans conformers. So we have to concentrate on what happens in the amorphous domains. The study of Van den Heuvel had as result a description of the uncoiling of processes which take place. In region 1 entanglements (amorphous chain-chain interactions) of the molecular chains contribute substantially to the modulus. This leads to a maximum in modulus. In region 2, after the first maximum, the modulus reduces, which is caused by the break down of the entanglement network and the start of the uncoiling by gauche → trans transitions. This uncoiling takes of course place in the amorphous domain. The uncoiling effects a lowering of the non-elastic modulus, while in region 2 the elastic modulus increases.

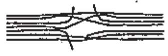
The uncoiling in region 2 leads to straining of the tie-molecules. The chain modulus of the taut-tie molecules is relatively high, which results in increase of the tensile modulus of the yarn. This increase continues up to the next maximum. When the modulus reaches its second maximum some of the taut-tie molecules begin to break, this is the start of region 3. The number of molecules that break is limited. (It is measured to be maximally 3%). The increased reduction of the modulus in region 3 is the result of chain scission in the amorphous zone where much more local stress concentrations are generated, which lead to further accumulation of molecular breakdown and which lead to rupture of the filament.

We can summarize this process as:

Region 1: entanglement of molecular chains result in high modulus.

Region 2: uncoiling of the molecular chains with gauche-trans transformation and straining of the taut-tie molecules.

Region 3: chain scission in amorphous zones leading to rupture.



This process has been measured and verified by means of various techniques as has been described by Van den Heuvel (1992).The process describes what happens during short term loading of a PET sample'.
Unquote.

The difference in the shape of the creep curves at various load levels can be explained with this method. In figure 1 the stress-strain curve and the modulus of the type 90 material are shown, also the creep during the 1 year testing is indicated for the various load levels.

In the modulus curve the various regions can be described:
0-0.8% entanglement of molecular chains result in high modulus.
0.8-2.5% entanglement and start of uncoiling of the molecular chains.
2.5-7% further uncoiling of the molecular chains by gauche -> trans transition and taut-tie molecules carry the load.
7-8% first part breakage of (3%) taut-tie molecules and stress concentrations in the amorphous zone and chain-scission as a result of it.

4 OBSERVATIONS (FIGURE 3)

When we study the results of the stress-strain curve of type 90 (figure 1) and the creep curves of figure 2 and 3 following observations can be made.

1. The creep measurement at 10% load is in the region 1.This means that the entanglement of the molecular chains has not yet completed and will further take place during creep loading. The result of this entanglement is an increase of elongation in time, up to the moment that all entanglement has taken place and the modulus has reached its maximum. Reduction of creep rate at the end of the test period may be expected and indications of it can be found at the end of the curve. The concave behaviour of the creep line in figure 3 is typical for region 1 and is also the result of our test.
2. The creep curves for 20, 30 and 40% have a convex shape. Further the amount of creep during the loading time of approx. 10,000 hrs. is maximal at load level 20% and reduces with every load step 30%, 40% and 70% (figure 1 and 3). This is contrary to what one would expect but it is in line with the molecular changes. At 20% load level the sample is in the strain zone between 1,5 and 2,8%. This is the zone of reduced modulus caused by the entanglement of the molecular chains and especially in the zone with the lowest modulus, consequently the elongation will be greater than in the zones with higher modulus.

   At 30% the modulus is between the value of 20 and 40% load level. This is represented by the values of the creep as indicated in figure 1. The higher load levels are close to the 2nd maximum and 75% is more or less at the maximum. In the creep curves we observe the start of an upswing which indicates a reduced modulus and entrance of the loading/strain condition in region 3.
3. In the other paper on this conference it is shown that as a result of the creep process the elongation at break reduces, the modulus of the curve becomes higher and the location of the 2nd maximum moves forward to lower strain levels. Figure 7 shows the creep results of the SIM test on geogrid type 90. That is the group of measurements at the high load levels and indicated as VD.

We see here that the upswing of these curves start between 6 and 7% elongation. This is in line with the described behaviour of the molecular chains. On the other hand we may not draw decisive conclusions from these measurements as they are made at elevated temperatures which influence the modulus as shown in the study by Van den Heuvel (1993).

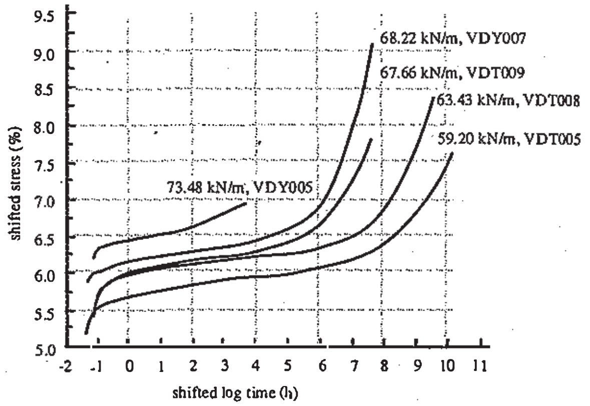


Figure 7. Creep at high loads using SIM testing method.

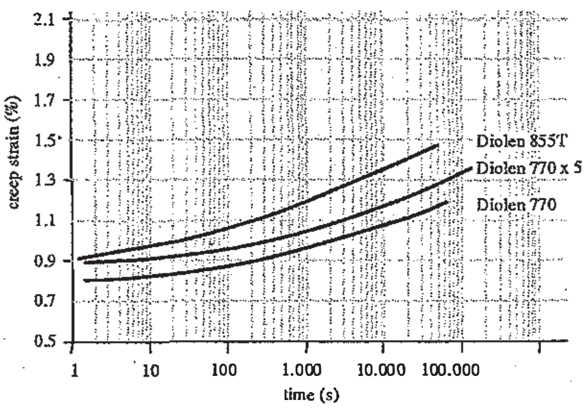


Figure 8. Creep of Diolen yarns at 10% load level.

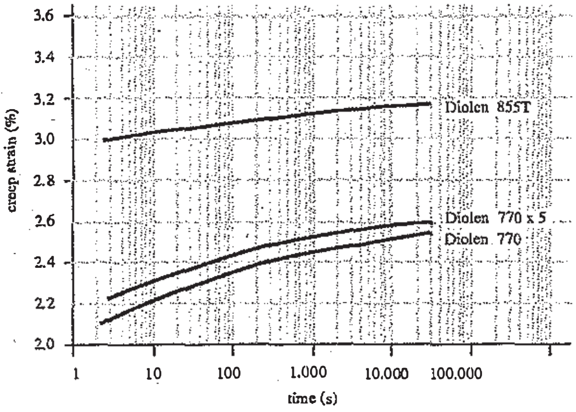


Figure 9. Creep of Diolen yarns at 20% load level.

5 VERIFICATIONS OF THE RESULTS

In 1985 a series of very detailed creep tests have been made at the Akzo Nobel Research laboratory on 2 types of Diolen yarns (type 855T and 770). The results of this study showed exactly the same behaviour as mentioned above for PET straps. Figure 8 and 9 show the results.

Another conclusion of this study was that the creep rate in the first 10,000 seconds (on log scale) was much higher than afterwards and it became steady after this point. These measurements on different PET yarns show the same concave and convex shape of the creep curve for 10 and 20% as was shown with PET straps. In our other paper on this conference we have published supporting data gained from the residual strength and stiffness of other PET yarns. Altogether we consider the presented description of polymer changes during loading as very realistic. This system can also be used for evaluation of long term extrapolations of data.

6 QUICK BUT ACCURATE CALCULATION OF TOTAL CREEP

The data from the tests on straps as well as those on PET yarns show that after 10,000 seconds or 2,78 hrs. the creep rate becomes steady (at log scale).

This observation is important for future creep testing. The total strain curing a certain service life consists of :

$$\Sigma_t = \Sigma_e + \Sigma_2 + \Sigma_c$$

Σ_t = total strain
Σ_e = elastic strain during loading
Σ_2 = creep during 10,000 s
Σ_c = creep during the rest of the service life.

The Σ_e and Σ_2 can be measured rather easy with a stress-strain tensile test and with the same equipment but now keeping the load constant for 3 hours. In this way we get very quickly Σ_e and Σ_2.

The creep rate Σ_c is rather constant during the rest of the service life using a log scale for the time. For example: the measurement at 30% of the PET strapping.

$\Sigma_e = 3.35$
$\Sigma_2 = 0.45$

The creep rate in the next part of the graph can be calculated as 0,2% over 2 decades which is 0,1% per decade. If the lifetime is 100 years or 876,000 hrs. then, log t (hrs.) = 5,94.

The log t at the end of Σ_2 period is log (166 hrs.) = 2.22.

The expected creep can be calculated as:
log t: 5,94 – 2,22 = 3,72 or 3,72 decades.
$\Sigma_c = 3.72 * 0.1 = 0.37\%$

The total deformation is then $\Sigma_t = 3.35 + 0.45 + 0.37 = 4.17\%$.

7 CONCLUSIONS

1. Creep curves of PET at 10% loading have a concave shape and above 20% a convex shape.
2. The description of the molecular chain behaviour under stretching as published by Van den Heuvel can be used to explain this behaviour.
3. This description is also applicable for description of the creep process of PET material.
4. The elongation under constant loading can be divided in 3 sections: elastic strain, zone of strongly reducing creep rate up till 10,000 s, zone with creep rate constant. These sections are applicable for all loading cases as long as the total strain remains below the 2nd maximum of the modulus of the stress-straincurve.
5. Using the method of 3 creep zones it is easy and it does not require large creep testing equipment or prolonged creep testing to determine the total strain during the service life of a PET reinforcement material.

REFERENCES

Den Hoedt, G., 1986, Creep and Relaxation of Geotextile Fabrics, *Geotextiles and Geomembranes Vol. 4, page 83-92.*

Viezee, D.J. c.s., 1990. Designing soil Reinforcement with Woven Geotextiles, 4th International Conference on Geotextiles, Geomembranes and Related Products, The Hague, page 651-656.

Voskamp, W. How to determine the long-term design strength of reinforcing mats 1985, Yearly conference of the Institution of Civil Engineers in Hong Kong, Hong Kong.

Thornton, J.S. c.s., 1997. Approaches for the prediction of Long-Term Viscoelastic Properties of Geosynthetics from Short-Term Tests, *Geosynthetics 1997 Conference Proceedings, St. Paul, Minn., page 277-291.*

Voskamp, W. 2000. Index and Performance testing of a new geogrid made of highly oriented straps, Advances in Transportation and Geo-environmental Systems using Geosynthetics ASCE Geotechnical Special Publication no. 103, Denver, USA.

Greenwood, J., Voskamp, W., 2000. Predicting the long-term strength of a geogrid using the stepped isothermal method. *2nd EuroGeo, Bologna Italy, page 329-332.*

Voskamp, W. c.s., 2000. Residual Strength of PET after more than 12 years creep loading, *3rd IS Kyushu Conference on Earth Reinforcement, Kyushu, Japan.*

Van den Heuvel, C.J.M. c.s., 1993. Molecular changes of PET yarns during stretching measured with Reo-Optical infrared spectroscopy and other techniques, Journal of Applied Polymer Science.

Van der Bleek, I.M.C., 1985. Creep of Diolen Yarns. Internal report Akzo Nobel Research Laboratories.