BAM

Bundesanstalt für Materialforschung und -prüfung

Provisional Guidelines for the Certification of Polymeric Geogrids for Landfill Capping Systems

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These provisional Certification Guidelines and the list of certified geogrids, as well as additional Guidelines for geosynthetics and leak detection systems based on the German Landfill Regulations and lists of products certified under these Guidelines, can be downloaded as pdf files from the websites:

http://www.tes.bam.de/en/mitteilungen/abfallrecht/index.htm

http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

For the certification procedure the requirements of the currently valid German version of the Certification Guidelines are mandatory.

Foreword

The new Landfill Ordinance (DepV) came into force on 16 July 2009. It was most recently amended by clause 2 of the ordinance for the implementation of the modified waste-legislative criteria of hazardousness, dated 4 March 2016. The current version stipulates in Annex 1 no. 2.1 of the Landfill Ordinance that materials, components or systems may be used in the sealing system only if they comply with the state of the art in accordance with Annex 1 no. 2.1.1 and if this has been demonstrated to the responsible authority. For geosynthetics, polymers and serially produced seal-monitoring systems, certification by the BAM (Federal Institute for Materials Research and Testing) according to Annex 1 No. 2.4 is proof that these materials, components or systems satisfy this requirement.

Notwithstanding this, materials, components or systems which have been declared on the basis of harmonized European technical specifications for the EU Construction Products Directive may be used in landfill-liner systems if the material, component and system characteristics specified in the harmonized technical specifications are substantially equivalent to those arising from the requirements of the Landfill Ordinance as regards state of the art. At present there are no harmonized European technical specifications which fulfill the state-of-the-art requirements of the Landfill Ordinance, in particular as regards long-term performance.

In addition, materials, components or systems can be used in landfill-liner systems if they have been legally manufactured or placed on the market in another EU Member State or in Turkey in accordance with the regulations or requirements in force there, or if they have been legally manufactured and placed on the market in another Signatory State to the Agreement on the European Economic Area in accordance with the regulations or requirements in force there, if the tests and inspections in the country of manufacture confirm that the material, component and system characteristics guarantee in the long-term a level of protection equivalent to that required by the DepV Landfill Ordinance. When considering relevant evidence, the competent authorities may contact BAM for technical support.

The procedure for certification is laid down in No. 2.4 of Annex 1 of the DepV. The tasks of the BAM in No. 2.4.1 include the definition of test criteria, the adoption of additional provisions into the certification and in particular the determination of requirements for professional installation and for quality management. As outlined in No. 2.4.4, an Advisory Council is involved in establishing appropriate Certification Guidelines.

After the Landfill Ordinance came into force on October 16, 2009, the Advisory Council was constituted and established a working group which drew up these initially only provisional new Guidelines for the Certification of polymeric geogrids for landfill-capping systems. The Guidelines are described as provisional for two reasons: Firstly, because polymeric geogrids are made from a variety of materials and with very different structures. The information available on the properties of individual geogrids varies from type to type. Until now, the Certification requirements have therefore concentrated mainly on woven grids and strip grids made of polyester (PET) or polypropylene, and on extruded geogrids made of high-density polyethylene. Secondly, in connection with the Certification procedure, experience needs to be gained with new tests, in particular with those concerned with the long-term behavior of the junctions between the longitudinal and transverse grid members, as these form the basis of a complete and accurate assessment. The existing uncertainties are therefore provisionally still reflected in the "conservative" stipulation of reduction factors and additional restrictive requirements on the design. The provisional nature of the Guidelines can be lifted as soon as the level of knowledge about the long-term behavior of reinforcing geogrids permits this.

The following persons took part in the discussions:

1. The members of the Advisory Committee:

Dipl.-Ing. K.-H. Albers, *G quadrat Geokunststoffgesellschaft mbH*; Dipl.-Ing. W. Bräcker, *Staatliches Gewerbeaufsichtsamt Hildesheim*; S. Baldauf, *GSE Lining Technology GmbH*; Dipl.-Ing. R. Drewes, *Landesamt für Umwelt Brandenburg*; Dipl.-Ing. K. J. Drexler, *Bayerisches Landesamt für Umwelt (LfU);* H. Ehrenberg, *NAUE GmbH & Co. KG;* Dipl.-Ing. A. Elsing, *HUESKER Synthetic GmbH*; Dr.-Ing. B. Engelmann, *Umweltbundesamt*; Dipl.-Ing. F. Fabian, *Landesanstalt für Umwelt, Messungen und Naturschutz, Baden-Württemberg*; Dipl.-Geoöko. K. Heinke, *Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie*

(LfULG); Dr.-Ing. D. Heyer, *TU München, Zentrum Geotechnik*; Dipl.-Ing. M. Müller, *Landesamt für Umweltschutz Sachsen-Anhalt;* Dr. rer. nat. W. Müller, *Bundesanstalt für Materialforschung und –prüfung (BAM)*; Dr.-Ing. E. Reuter, *IWA Ingenieurgesellschaft für Wasser- und Abfallwirtschaft*; Dipl.-Ing. P. Riegl, *GEO-POLYMER Trading e.U.*; Dipl.-Ing. G. P. Romann, *AGAS Arbeitsgemeinschaft Abdichtungstechnik e.V.*; Prof. Dr.-Ing. F. Saathoff, *Geotechnik und Küstenwasserbau, Universität Rostock*; Dipl.-Ing. T. Sasse, *Umtec | Prof. Biener | Sasse | Konertz*; Prof. Dr. F.-G. Simon, *Bundesanstalt für Materialforschung und –prüfung (BAM)*; Dr.-Ing. M. Tiedt, *Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen*; Dipl.-Ing. L. Wilhelm, *Thüringer Landesanstalt für Umwelt und Geologie*; Dipl.-Ing. Ch. Witolla, *Ingenieurbüro Geoplan GmbH*; Prof. Dr.-Ing. K. J. Witt, *Fakultät Bauingenieurswesen, Bauhaus-Universität Weimar*; A. Wöhlecke, M. Eng., *Bundesanstalt für Materialforschung und –prüfung (BAM)*; Dipl.-Ing. K. Wohlfahrt, *Bonar GmbH & Co. KG*; Dipl.-Ing. H. Zanzinger, *SKZ Süddeutsches Kunststoff-Zentrum*.

2. Other members of the Working Group:

Dr.-Ing. D. Alexiew, *HUESKER Synthetic GmbH*; Dipl.-Ing. A. Herold, *IBH – Herold & Partner Ingenieure*; Prof. Dr. Müller-Rochholz, *KIWA TBU GmbH*; Dipl.-Ing. O. Naciri, *Tensar International GmbH*; Dipl.-Ing. Ch. Recker, *SINTEF;* Dr.-Ing. J. Retzlaff, *GEOscope GmbH & Co. KG*; Dipl.-Ing. L. Vollmert, *BBG Bauberatung Geokunststoffe GmbH*.

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1. Legal Basis, Area of Validity and Regulations

The protection of people and the environment against the generation and management of waste is now regulated by the new Waste Management and Product Recycling Act (KrWG) introduced on February 24, 2012. On 16 July 2009, a new Landfill Ordinance (DepV) was brought into force on the basis of the recycling and waste management legislation. The DepV was most recently amended by clause 2 of the ordinance for the implementation of the modified waste-legislative criteria of hazardousness, dated 4 March 2016. Annex 1, No. 2.1 of the DepV permits the use in sealing systems of state-of-the-art geosynthetics (geomembranes, geocomposite protection layers, geocomposite drain elements, plastic reinforcing grids, etc.), of polymers, and of serially produced leak detection systems which correspond to No. 2.1.1 and which have been certified by BAM according to No. 2.4.

In accordance with No. 2.4.1 and on the basis of its own investigations and those of accredited bodies, BAM is responsible for the testing and certification of geosynthetics, polymers and leak-detection systems for use in base and cap sealing of landfills. In this context, it has the following tasks:

- the definition of test criteria,
- the inclusion of additional provisions in the certification, and
- the establishment of requirements for proper installation and quality management.

On this legal basis, and taking into account the requirements referred to in No. 2.1.1 of Annex 1 of the DepV regarding state of the art, these Guidelines describe the requirements for the Certification of polymeric geogrids in landfill-capping systems. The Guidelines are the technical basis on which BAM, at the request of the manufacturer, tests the suitability of polymeric geogrids and then confirms this suitability by issuing a Certification Document.

Landfill sealings must be executed according to the current state of the art. These Guidelines therefore describe the requirements to be met for the installation of certified geogrids so that the final sealing system corresponds to the state of the art. The Certificates explicitly refer to these requirements. The competent (federal) State authorities must ensure that these additional provisions form part of the approval of the landfill and are therefore legally binding. Only if this condition is fulfilled can the BAM Certificate be used as proof of the suitability of state-of-the art sealing systems constructed with the geogrids.

The Certification is issued expressly subject to revocation. Grounds for revocation are given if the manufacturer deviates from the procedures specified in the test reports and appendices of the certification document, from the raw materials as used in the sample tested or from other requirements specified in the certification document. Should this be the case, further production of any geotextile using the BAM Certification number is prohibited.

Changes in either the raw material or the production process of the polymeric geogrids or dispositions for in-house quality control and third-party inspection of production require new Certification. If production processes or installation procedures used by the manufacturer do not prove themselves in practice and this can be demonstrated by new technical findings, i.e. if the factual situation, the state of the art and the legal situation have changed such that Certification can no longer be issued, this too is grounds for revocation.

In the event of revocation the manufacturer is obligated to return the Certification document immediately to the Certification Authority.

The Certifications are based on the following laws, regulations and guidelines in their currently valid versions:

- Act for the Promotion of Recycling of Materials and the environmentally compatible Disposal of Waste (Waste Management and Product Recycling Act - KrWG) of 24 February 2012, Bundesgesetzblatt (BGBl, Federal Law Gazette) Part I, No. 10. pp. 212-264.
- Regulation on Landfills and long-term Storage (Landfill Ordinance – DepV); Article 1 of the Regulation on the Simplification of Landfill Legislation of 27 April 2009 (BGBl I No. 22 of 29 April 29 2009 p. 900), most recently amended by clause 2 of the ordinance for the implementation of the

modified waste-legislative criteria of hazardousness, dated 4 March 2016. (BGBl. I No. 11 of 10 March 2016 p. 382).

- First Regulation amending the Landfill Ordinance of 17.10.2011; BGBI 2011, Part I, No. 52, pp. 2066-2079.
- Guidelines for the Qualification Requirements and the Tasks of third-party Inspectors in the Installation of Plastic Components and Parts in Landfill-Sealing Systems (Guidelines for External Inspectors), BAM Federal Institute for Materials Research and Testing.
- Guidelines for Requirements on Specialist Contractors for the Installation of Geomembranes, other Geosynthetics and Plastic Components in Landfill-Sealing Systems (Guidelines Installation Contractors), BAM Federal Institute for Materials Research and Testing.
- Guidelines for the Certification of Leak Detection Systems for convection barriers in Landfill Cap-Sealing Systems, BAM Federal Institute for Materials Research and Testing.
- Guidelines for the Certification of Separation and Filter Geotextiles in Landfill-Sealing Systems (Certification Guidelines Geotextiles), BAM Federal Institute for Materials Research and Testing.
- These Guidelines for the Certification of Geomembranes to line Landfills (Certification Guidelines GM), BAM Federal Institute for Materials Research and Testing.
- Guidelines for the Certification of Geocomposite Drains in Landfill Capping Systems (Certification Guidelines Composites Drains), BAM Federal Institute for Materials Research and Testing.
- Guidelines for the Certification of Protection Layers for Geomembranes in Landfill-Sealing Systems (Certification Guidelines Protection Layers), BAM Federal Institute for Materials Research and Testing.
- Provisional Guidelines for the Certification of Plastic Reinforcement Grids for Landfill Capping-Systems (Provisional Certification Guidelines Geogrids), BAM Federal Institute for Materials Research and Testing.

The relevant dates of issue of the quoted standards are specified in section 9.

2. Objects Certified

2.1. General

The Certification applies to polymeric geogrids[1] used in landfill-sealing systems to guarantee their stability[2]. The term polymeric geogrid refers to a planar polymeric structure consisting of a regular, open network of longitudinal and transverse elements. The openings in the network are usually larger in area than the elements surrounding them. With respect to the manufacturing process, a distinction is made between woven, warp-knitted, drawn, and strip geogrids[3]. The longitudinal and transverse elements are connected to one another by extrusion, welding, interweaving or other methods. In the case of drawn geogrids, a grid is stamped out of an extruded sheet and then usually uniaxially or also biaxially drawn. The strip geogrid are produced by superposing previously manufactured grid elements and then joining these at their contact points by a variety of methods. The grid elements of woven or warp-knitted geogrids are intertwined with one another. A junction is defined as the place at which the longitudinal and transverse elements of the grid intersect/overlap and are joined together.

The interaction of geogrid and soil results from the interlocking of soil particles with the openings of the grid and from the friction between the soil particles and the surface of the grid elements, cf. Section 4.4.

For a particular type of reinforcement grid, the manufacturer usually offers a complete product family. The products in the family are similar to one another and are manufactured using the same process, in the same manufacturing plant, and of the same materials. However, they differ in the dimensions of the cross section of the elements, the weight per unit area, and in their strength character-

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[1] Referred to hereafter as geogrids.

[2] See the GDA recommendation E 2-7 "Verification of stability of sealing systems opposite sliding", and

EBGEO, Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements, Verlag Ernst und Sohn, Berlin, 2010.

The GDA recommendations area available on the website www.gdaonline.de.

[3] GDA Recommendation E 2-9 "Application of Geotextiles in Landfill Construction".

istics.
A prerequisite for the application of the certified geogrids is that the temperature in the vicinity of the installed product is similar to typical soil temperature conditions (mean temperature ≤ 20° C). As a rule, therefore, the geogrids can only be used above the sealing components or outside the actual surface sealing: In Germany, climatic conditions mean that a continuous temperature of 15° C is rarely exceeded in the lower zone of soil layers with a thickness of at least 1 m. In the transition zone of the sealing to a recultivation layer with a minimum thickness of 1 m, the temperature requirement will therefore generally be fulfilled, even if it is assumed that temperatures up to 30° C may occasionally occur in the sealing components themselves. Restrictions on the application may still arise from the permissible pH values around the geogrid. Geogrids made of polyester (PET), for example, may usually only be used in environments with a pH in the range of 4 to 9.
The use of a Landfill Ordinance-certified product is always binding if the reinforcement contributes permanently to the stability of the sealing system. The two most important examples of this are the stability of the surface-sealing system against sliding parallel to steep slopes, and the reinforcement of a supporting embankment at the foot of a sealed landfill mass.
As a matter of principle, a geogrid certified on the basis of these Guidelines is also suitable for use in stabilizing contaminated sites and for the sealing of capping layers of landfills not subject to the Landfill Ordinance.
The certified geogrid must be factory manufactured with defined, reproducible properties.
Applicant and Certification Holder is the manufacturer of the geogrid.
The geogrid must be fully and unmistakably described by the applicant. This includes a description of the geogrid and of any relevant pre-products used, exact details of the type and specification of materials and type and quantity of polymer-bound additives (masterbatch) or other additives used in the production of intermediate products and the product itself, a description of the manufacturing process, and information on the characteristic properties of the product.
In the Certification Document, the object certified is exactly described by its dimensions and the short-term tensile strength as well as by the information detailed below.
The geogrid must have a CE mark referring to DIN EN 13257. Its production must be subject to in-house and third-party inspection within the framework of a quality management system certified according to DIN EN ISO 9001.
The Certification Authority must be notified of and approve any changes in the above. Should such changes not be notified, the Certification becomes invalid.

2.2. Material and properties of the geogrid pre-products

The following details must be confidentially deposited with the Certification Authority:

- Resin manufacturer and resin type designation of the pre-product (e.g. extruded sheets or flat strips, filaments, multifilament yarns etc.), from which the geogrid is made, with the manufacturer's specifications for the density and the melt mass-flow rate as well as further information on the resin (molecular mass distribution, additives),
- Manufacturer and formulation of polymer-bound additives (masterbatch) and other processing aids,
- Additional details must be disclosed if these are necessary for the unambiguous definition of the material.

The applicant has to provide sample material of the molding compound, of masterbatches and the other processing aids.
There must be a legally binding agreement between the manufacturers of the pre-products and the manufacturer of the geogrid concerning the specification of all materials used. In an Annex to the Certificate, the Certification Holder must submit a legally binding statement of the materials used. The clear definition of the materials, the verifiability by the Certification Authority of the information given, and the possibility of verification testing against the specified values is required as a matter of principle before Certification can be awarded.
Fundamental properties of the pre-products and their specification (mean value and permissible tol-

erances) are specified in the Certification Document, insofar as they are not subject to secrecy. The fundamental properties are checked in the in-house QC of the pre-product manufacturer, and in the goods-received control, the in-house QC and the external quality control of the manufacturer of the geo-grids (see Table 5).

The characteristic properties of pre-products are specified in Table 1. Other pre-products may have different fundamental properties, which may be stipulated on a case-to-case basis based on this Table.

2.3. Properties of the geogrid

The Certification Document lists the characteristic properties of the geogrid based on DIN EN 13257 in terms of the design requirements (see Table 2 and Section 3). These properties are checked in the in-house and third-party production quality control of the geogrid. To this end, the characteristic values for the assessment in the context of in-house and third-party inspection are laid down in the Certification Document. The characteristic values are derived from the mean value and the permissible tolerance, these being specified by the manufacturer on the basis of a statistical evaluation of his own measurement results, or taking into account safety factors based on experience[4].

Since the products must have CE labeling, the characteristic values for the characteristic properties can be taken from the CE declaration of performance.

Section 3 details the approval requirements for certain characteristic properties.

The data sheet of the geogrid must document at least the data relevant for in-house quality control.

[4] The procedure for determining the "permissible tolerance" of a property of a product, which has to be declared within the framework of the CE marking, is not precisely defined. It results from the procedures and requirements of the factory production control. Here, manufacturers take different approaches. Often, a mean value over the width of the sample and the corresponding standard deviation are specified, and compliance with these is guaranteed by the factory production control. In the context of the current application standard, however, users mostly understand the term to mean that 95 % of the test results for a large number of individual tests of this property will lie within the tolerance range (95 % confidence interval).

2.4. Marking

The certified product must be marked and packaged with repeated identification marking according to DIN EN ISO 10320. The approved product type must be clearly apparent from the marking on the product (e.g. by colored marking or coloring of elements according to a certain system (color code)). The marking must be printed so that it is clearly legible at the time of installation. Each unit (roll) must carry a label in accordance with DIN EN ISO 10320 which gives in particular the name of the manufacturer, the type of product or the product name, the type designation, the Certification number, the dimensions, the weight, as well as an internal company code (roll number), and from which directly or indirectly the date of production can be read and which enables the results and documentation of quality assurance procedures to be assigned to the delivery unit in a unique way. Further information can be required in individual cases. A generic label is attached to the Approval Certificate as an annex.

2.5. Manufacturing Plant and Manufacturing Process

The manufacturing plant and a manufacturer's description of the manufacturing process are fixed and form part of the Certification Document. All special details on the manufacturing process are confidentially deposited with the Certification Authority. Prior to issuing certification, the Certification Authority will visit the manufacturing plants of both the geogrid and the pre-product manufacturer to verify the information provided on the manufacturing process and machines and to verify that qualified staff, rooms, test and other equipment on the manufacturing plant and in the testing laboratories ensure flawless production and in-house manufacturing QC in line with requirements.

In individual cases, the manufacturer must demonstrate how potential production defects resulting from the chosen manufacturing process are prevented by applying appropriate measures in the production process and in quality management.

3. Characteristics of the Geogrid for Design Purposes

The geogrid must fulfill its function for at least 100 years. A design must assess the load acting on, and the probable material resistance of the geogrid after 100 years of the geogrid, compare these with one another and verify whether this requirement is met. The stability calculation, which is based on the design rules of EBGEO[5] (see Section 8), leads to requirements on certain design values of the material resistance of the reinforcement which must be met or exceeded by the chosen geo-grid. These are the design value of long-term tensile strength of the geogrid, the design values of frictional resistance for the friction between the soil or geosynthetics and the geogrid for the failure mechanisms "shearing/sliding" (see EBGEO, section 2.2.4.11) and – extending the EBGEO design rules – the design value of the interaction coefficient and the long-term pull-out resistance[6] (long-term maximum "anchorable" tensile force due to the long-term strength of cross-members and junctions) and the corresponding anchorage length for the failure mechanism "anchoring/pullout". In addition, the long-term deformations and displacements resulting from the actions must be determined and it must be assessed whether these are "compatible with the purpose of the structure". Thus, the geogrid must be selected so that it will retain sufficient strength and also remain fit for purpose over a service life of at least 100 years.
Using prescribed, load case-dependent safety factors, these design values are attributed to characteristic property values of the geogrid, which can either be determined in tests or calculated from test values with reduction factors. These include:

[5] EBGEO, Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements, Verlag Ernst und Sohn, Berlin, 2010.

[6] Müller, W.: Zur Bemessung der Verankerung von Bewehrungsgittern aus Kunststoff beim Schutz von Böschungen vor hangparallelem Gleiten. Bautechnik, 88(2011), H. 6, pp 347-362.
Müller, W.W., 2014. Long-term pull-out resistance and materials properties of geogrids, in: Ziegler, M., Bräu, G., Heerten, G., Laackmann, K. (Eds.), Proceedings of the 10th International Conference on Geosynthetics. German Geotechnical Society (DGGT), Essen, Germany

1. the characteristic value of residual tensile strength $R_{B,k}$, available after a long period of time
2. the isochrone curves,
3. the characteristic value of the friction coefficient $f_{sg,k}$ or $f_{gg,k}$ for the "friction" between soil and geogrid or for the friction between geogrid and another geotextile for the failure mechanism "shearing/sliding",
4. the characteristic value of the interaction coefficient λ for certain soils and surcharges, and the long-term allowable pullout resistance and the minimum required anchor length for the failure mechanism "pullout/anchorage".

Under 1).: The long-term tensile strength $R_{B,k}$ derives from the characteristic short-time tensile strength $R_{B,k0}$ which is calculated from the mean value of tensile strength and the scatter of the measured values determined in a given number of tensile tests according to DIN EN ISO 10319, applying reduction factors according to the equation:

$$R_{B,k} = \frac{R_{B,k0}}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5}.$$

Here, the reduction factors 1 to 5 should be experimentally so determined that the influence of the following loads can be assumed to be estimated on the safe side:

A_1 Creep and ductile failure,
A_2 Damage during transport, installation, and compaction,
A_3 Weak points resulting from junctions, seams, connections, connections to components,
A_4 Environmental influences, weather conditions, internal and external aging processes or other non-mechanical stressing,
A_5 Dynamic mechanical stressing.

The reduction factors A_3 and A_5 need not be considered for Certification in landfill construction. As a matter of principle, the transfer of forces via joints, seams, connections, or connections to structures is not permitted in reinforcement measures in the area of surface sealings. Dynamic stressing needs to be

considered to some extent for a short period only in the construction phase. With regard to the necessary verifications for the reduction factor A_2 see Section 2.2.4.6.2 and Section 8 of EBGEO. The Certification Document indicates $R_{B,k0}$ as well as the reduction factors A_1 and A_4, and also gives typical examples of A_2.
As a matter of principle, Certification can only be granted if long-term trials have been performed which allow quantitative assessment of the effects of creep and ductile failure (reduction factor A_1) and the retroactive effect of the aging processes and weathering on the strength (reduction factor A_4). It must be shown here that no serious adverse change in the creep behavior and bearing strength for a service life of 100 years takes place due to the aging (see here the next Section 4.3).

Under 2).: To produce a diagram of the isochrone curves, creep tests are performed to investigate what tensile forces result in what strains after what times. For a given time, the isochrone curve then represents the functional relationship between the "utilization factor" (i.e. tensile force per sample width/short-term tensile strength) and the strain. The isochrone curve for 100 years is extrapolated from the curves for shorter times. The isochrone diagram is shown in the Certification Document. Again: as a matter of principle, Certification can be granted only if there are long-term experiments which confirm that the adverse effect of the aging processes on the deformation behavior can be estimated: No serious adverse changes in the deformation behavior may occur due to the aging.

Under 3).: Typical values of the characteristic friction parameters for friction between geogrid and geosynthetics, and between geogrid and soil for the failure mechanism "sliding/shearing" are specified in the Certification Document. It is generally assumed that the friction parameters do not change over time. This assumption appears to be justified if the frictional resistance is generated by the friction between the soil particles or the surfaces of the geosynthetic and the surfaces of the grid elements in their contact area. Initially, aging processes will adversely change only the strength properties. Only at a very advanced stage would the surface properties also change to an extent that would affect the friction.

Under 4).: In EBGEO it is assumed that the interaction between geogrid and soil in a pullout situation can be regarded as a type of friction on which the tensile strength and junction strength of the geogrid or on age-related changes in the material have no influence . The friction is characterized by an "composite coefficient of friction" which is determined in the pullout test. In the design it is then assumed that, for a given coefficient of friction, the pullout resistance increases in proportion to the normal stress, the characteristic friction of the soil and the anchor length, and thus the tensile force to which the geogrid may be subjected can always be anchored, as long as the anchor length or the superimposed normal stress are chosen large enough. This approach, however, applies only to a completely rigid geogrid, in which the mechanical strength of the junctions and transverse elements is much greater than the highest tensile and shear stresses which have to be transferred from the geogrid elements into the soil. In the limit state, when pullout is just commencing, the rigid, intact geogrid plows through the soil, and the force required for this does indeed increase in proportion to the vertical stress and the embedded length. This approach continues to apply in the special case in which only the surface friction over the contact surface between the soil particles and longitudinal members actually determines the pullout resistance (frictional grid). This prerequisite is generally not satisfied by synthetic geogrids[7].
Because of the limited stiffness of the longitudinal plastic elements, a pullout force will only be distributed along a certain activated length, irrespective of the actual embedded length. The junctions, which transfer to the longitudinal elements the earth pres-

[7] Ziegler, M., Timmers, V.: A New Approach to Design Geogrid Reinforcement. In: Proceedings of the Third European Geosynthetic Conference. Floss, R., Bräu, G., Nußbaumer, M. and Laackmann, K. (Hrsg.), DGGT and TUM-ZG, München, 2004.
Müller, W.: Zur Bemessung der Verankerung von Bewehrungsgittern aus Kunststoff beim Schutz von Böschungen vor hangparallelem Gleiten. Bautechnik, 88(2011), H. 6, pp 347-362. Müller, W.W., 2014. Long-term pull-out resistance and materials properties of geogrids, in: Ziegler, M., Bräu, G., Heerten, G., Laackmann, K. (Eds.), Proceedings of the 10th International Conference on Geosynthetics. German Geotechnical Society (DGGT), Essen, Germany

sure at the front of the transverse elements and the friction forces acting on the surface of these elements, are thus subject to different amounts of loading: The deformation and the tensile force to be transferred are relatively higher in the front zone, and reduce towards the end of the activated length. The upper limit of pullout resistance is thus determined by the strength of the junctions and the transverse elements. The force generated by the earth pressure which must be transmitted by each junction is small and in the order of several hundred Newtons. Under the specific loading conditions in the soil, however, the strengths of the junctions are not necessarily always much greater. How big they are depends on the type and characteristics of the particular geogrid.

The strength, deformation, and long-term behavior of the junctions (and the transverse elements) under the specific stressing in the soil under a certain superimposed normal stress determine the achievable pullout resistance and the minimum anchor length required to achieve this. It follows that, in general, the permissible pullout resistance and the minimum anchor length cannot be calculated on the basis of the composite coefficient of friction determined experimentally in the pullout test. This is possible only for a frictional geogrid. In the Certification process, therefore, it is not only the strength of the material of the longitudinal members which must be assessed, and the permissible tensile force derived from this to which the reinforcement grid may be subjected long-term. The strength of the material of the transverse, and in particular of the junctions, must also be assessed and from this the actually anchorable tensile force and the corresponding anchor length must be estimated. Certification requires that these two different material resistances (junction strength and strength of transverse elements) are also taken into account in the design.

When talking about junction strength, the strength under the specific stressing mode in the soil is usually meant. In addition, strength properties of junctions can be determined in tensile-shear tests in the laboratory. The testing of these properties in the laboratory is important for quality assurance. It can also be used as an index test for aging tests. But the values of the laboratory strength testing on junctions are not necessarily an indication of the behavior of the junction in soil. The requirements on the properties of junctions, and their long-term behavior, are described in greater detail in Section 4.3.4. For transverse elements, the same requirements usually apply to the long-term behavior as for the longitudinal elements (Section 4.3). Section 4.4 deals with the coefficients of friction for sliding/shear and pullout resistance. Section 7 makes suggestions which, depending on the characteristics of a geogrid, must be considered in an anchor design which will guarantee long-term stability.

4. Requirements on the Geogrids

The following describes the Certification requirements for the properties of the geogrids. The tests are carried out by BAM in Division 4.3 and in test institutes approved by BAM (Section 11 gives a list of test institutes approved to date). Tests are carried out on the general physical and mechanical properties, on the mechanical properties (tensile test), on creep behavior under tensile load, on durability, on the interaction with soil, on aging, and on the properties of the junctions.

In substantiated individual cases the certifying body may make special regulations which supplement or vary from the technical requirements defined in these Guidelines. These special technical requirements are drawn up after consultation and discussion with the Advisory Council.

4.1. General physical and mechanical properties

The characteristic properties of pre-products are addressed in Table 1. The selection of the tests required depends on the materials and the nature of the pre-products. In-house procedures and related test requirements are usually confidential to the manufacturer, and are treated as such by the Certification Authority.

The characteristic properties of a polymeric geogrid are compiled in Tables 2a and 2b. The tensile strength, the quality of the junctions, the isochrone curves, the creep-rupture behavior as well as the friction and pullout behavior are important properties with regard to the application of these products. The robustness against stressing during installation is a further important characteristic. Here, the associated test is regarded as confirmation of the suitability of the installation method. The other properties are used only for type identification, as general identifiers, and as benchmarks within the framework of quality assurance.

4.2. Basic durability tests

In *Guidelines on the durability of geotextiles and geotextile-related products* (ISO/TS 13434), published by the International Standardization Organization, "basic tests" for durability (hydrolysis, oxidation, attack by micro-organisms and weathering) are compiled, with which a minimum service life of 25 years is guaranteed (see Table 3). The tests assume that the products are used in an environment with pH 4 – 9 and a maximum temperature of 25° C. These tests are carried out in connection with the CE marking.

In addition to these basic tests, the stress-cracking resistance of the pre-product or the resin is determined, if stress cracking is of relevance for a geogrid due to the nature of the material and the way in which its components are formed (e.g. for geogrids extruded from resins sensitive to stress cracking), see Table 1 No. 14.

The geogrids must have a high resistance to weathering. They should however be exposed as little as possible to UV radiation, since this usually has a marked effect on plastics. UV radiation degrades the stabilization and can initiate auto-catalytic reactions which then continue even after the product is covered. Deviating from DIN EN 13257, the basic rule is therefore that all geosynthetics used in landfill construction, even those with high weathering resistance, must be covered at the end of each working day if possible, but no later than one week after installation.

Only geogrids which pass at least these basic tests can be considered for Certification purposes.

4.3. Long-term behavior

Materials and processes used in the production of the geogrid must be chosen so that the functional performance of the installed product is guaranteed under all external and mutually affecting influences in the capping layer for a period of at least 100 years. Here, the geogrid is systematically and permanently subjected to tensile forces. Special long-term studies are necessary to verify this very long service life. First, the behavior of the geogrid is examined in creep tests under tensile loads; from these, the isochronous stress-train curves are plotted and the service life achievable under different tensile loads is determined in creep-rupture tests (see Section 4.3.1). However, the test results can only be used in design if it can be shown that the material properties of the geogrid which determine its strength and deformation behavior will not change significantly over the course of 100 years. To this end, aging tests are carried out on unloaded samples. The design of these tests is based on the aging processes relevant for the particular material of the geogrid (see Section 4.3.2 and 4.3.3).

This procedure is justified only if it can be shown that the forces acting on the grid do not accelerate the aging processes and that no new failure mechanisms similar to aging are set in motion. If this condition is not met, the effect of the forces on the long-term behavior must be investigated in creep-rupture tests with "combined" stressing modes, i.e. combining creep and aging (see Section 4.3.4).

Finally, the junction zones of longitudinal and transverse members must be particularly closely examined since it is possible that the material behavior here may differ from that in the rest of the grid (see Section 4.3.5).

The program of investigation must also consider whether the longitudinal and transverse members are made of different materials, whether they are coated, or are made from a combination of several materials.

The long-term behavior of a geogrid depends on its material, its type and its structural design. There is therefore no "standard test" for all geogrids. Instead, for each product or product family a test program must be developed that takes into account the specific features of the product. Two cases can serve to illustrate this.

For a drawn geogrid of high-density polyethylene, material oxidation is the aging mechanism which determines service life. A state of stress induced by external forces will tend to slow the oxidation. This relationship is well documented. The warm-storage, immersion or autoclave tests described below can therefore be conducted (see Section 4.3.1). For this material, however, the applied forces may induce stress cracking. This mechanism could lead to material failure under the action of forces which are far below the level determined in the strength testing. Creep-rupture tests with "combined" stressing modes must therefore be performed. Stress cracking will probably occur in the less drawn junction zones of longitudinal and transverse members, and it is here that testing needs to be concentrated (see Section 4.3.4).

In a strip or woven polyester geogrid it will be necessary first to ascertain whether the selected polyester material is really resistant to oxidation and external hydrolysis under the environmental conditions pertaining in the landfill capping layer. The relevant aging process is then the inner hydrolysis (see Section 4.3.3). To this end, immersion tests can be carried out on unstressed samples, as here too a state of stress will probably not accelerate the hydrolytic degradation. This has already been confirmed in previous single investigations.

Next, the junctions must be investigated (see Section 4.3.5). If the elements are welded, the aging behavior and the strength of the welds must be determined in creep-rupture tests under "combined action", and test methods must be detailed with which the strength of the welds can be characterized. In the case of other junction types it must be considered what particular failure mechanisms may be appropriate and which test can be used to characterize these.

If necessary, specific requirements for the permissible stressing of the node areas must be set in addition to the permissible stressing of the geogrid.

For other materials and products (e.g. polypropylene strip geogrids, pultruded PE-PET geogrids or other multi-layer geogrids, woven PVA geogrids, etc.), a comprehensive test program taking all actions into account must be developed and applied.

4.3.1 Tensile strength and isochrone curves

Both creep tests and creep-rupture tests in accordance with DIN EN ISO 13431 must be performed (Table 2 No 2.9 and 2 10). The isochrone curves are determined from the creep tests. The creep-rupture tests are used to determine the reduction factor A1.

Tests lasting at least 10,000 h at a minimum of four load levels between 10 % and 60 % of the short-term tensile strength are required to create an isochrone curve for a product or for a product representative of a product family. The curves for 100,000 h and 1,000,000 h are extrapolated from the existing isochrone curves for times to 10,000 h.

For the certification of a product family, it must be proven that the isochrone curves of the products belonging to the family match those of the representative products. If this is not the case, the isochrone curves for each product must be determined. The following requirements apply to proof of conformity: Depending on the size of the product family, products with lower and higher short-term strengths are selected and tested in creep tests. Here, a creep curve at a minimum of two load levels is measured over a test period of at least 100 h. The data on the isochrone curve thus determined must not deviate significantly from the data of the representative product.

In order to produce a creep-rupture curve for a product or for a product representative of a product family, creep-rupture tensile tests must be conducted at a minimum of 12 different, evenly spaced tensile loads. The lowest tensile load must be chosen so that a time to failure of at least 10,000 h can be reached. The following requirements apply to proof of conformity: Depending on the size of the product family, products with lower and higher short-term strengths are selected and tested in creep-rupture tests. The tests are carried out with at least four different tensile loads. The lowest of these tensile loads must be chosen so that a time to failure of at least 1,000 h can be reached. The data on the time to failure curve thus determined must not deviate significantly from the data of the representative product.

Alternatively, the so-called Stepped Isothermal Method (SIM) in accordance with ASTM D 6992 can be used to determine the creep-rupture curve (Table 2 No. 2.11). The reliability of the results of the SIM tests must however always be confirmed by comparison with a conventional creep-rupture test (one tensile load, at least 10,000 h test duration).

4.3.2 Oxidation and leaching of stabilizers

The resistance to oxidative degradation for polyolefins is investigated in oven aging tests in a forced air oven in accordance with DIN EN ISO 13438 and in immersion tests in accordance with DIN EN 14415 at a storage temperature of 80 °C in each case (see Table 4 No. 4.1 and 4.2)[8]. The storage period must be at least one year. The changes in mechanical characteristics (maximum tensile strength and elongation at given tensile strength) are investigated, as are the antioxidant content and crystallinity. The antioxidant content is determined after a solid-liquid extraction by UV spectroscopy, HPLC analysis or indirectly by OIT measurements on the product itself. The measurement method selected depends on the type of stabilization. The crystallinity is determined by DSC measurement. The requirements are set out in Table 4.

Requirements for other raw materials/product types (e.g. polyester, polystyrene; PVC etc.) are set in analogy by transferring the requirements for resistance to oxidative degradation in Table 4.

The resistance to oxidative aging in polyolefins can also be verified by autoclave tests based on DIN EN ISO 13438 procedure C. Here, immersion tests are performed at an oxygen pressure of 5 MPa and at least three temperatures (60, 70 and 80 °C), and at 80 °C and at least two oxygen pressures (e.g. 1 and 2 MPa)[9]. The changes in the mechanical properties and in the stabilizer content are measured and used in estimating the expected service life under actual site conditions, according to a yet-to-be-determined procedure.

Since the oxidative aging leads to a gradual loss of strength, a reduction factor A_4 must also be determined here in analogy to the procedure described below for the hydrolysis.

[8] Müller, W. W., Jakob, I., Li, C4S. and Tatzky-Gerth, R.: Durability of polyolefin geosynthetic drains. Geosynthetics International, 16(2009), H. 1, pp. 28-42.

[9] Schröder, H. F., Munz, M. und Böhning, M.: A New Method for Testing and Evaluating the Long-Time Resistance to Oxidation of Polyolefinic Products. Polymers & Polymer Composites, 16(2008), H. 1, S. 71-80.

Note to the translation: Meanwhile research has clearly indicated that reliable results which map the aging behavior under usual conditions can only be achieved with test pressures well below 0.5 MPa.

4.3.3 Hydrolysis

The resistance to the aging process of inner hydrolysis is tested by immersion tests based on DIN EN 12447. The method of sampling and the mechanical tests is based on DIN EN 12226. Deionized water is used as the test medium. At five immersion temperatures (e.g. 50, 60, 70, 80 and 90° C), samples are stored for at least 10 extractions with at least 10 specimens from the longitudinal element including junctions, and if the properties of the transverse elements are different from the longitudinal, 10 additional samples from the transverse element including junctions. The tests must be performed over at least 10,000 h. The preparation, conditioning, storage and removal of samples are governed by an extra test specification. Coated samples may be stored only if random tests show that the coating has no influence on the test result for the range of test temperatures. Tensile tests to determine the maximum tensile strength, the elongation at maximum tensile strength, and the carboxyl end-group content or the limit viscosity number are performed on the extracted samples, these two latter being used as a measure for the reduction in mean molecular weight. The selection of the test method for the mechanical tests is based on DIN EN 12226 (draft). In addition, the glass-transition temperature is determined.

The data form the degradation curves for the tensile strength at different storage temperatures. For a given reduction in tensile strength, the associated storage periods are determined from the degradation curves. These times are plotted on an Arrhenius diagram and the expected service life under actual conditions is estimated by linear extrapolation. This is repeated for different reductions. The reduction factor for tensile strength A_4 is then so chosen that, with a probability of 95 %, the extrapolated expected service life at 20° C is greater than 100 years. The time-related molecular degradation at different temperatures is also evaluated. This allows the relationship between the reduction in the molecular weight and the tensile strength to be determined, and in particular the degradation curves at low temperatures to be checked.

An immersion test for the resistance to external hydrolytic degradation in polyester (PET) geogrids is described in Table 4 No. 4.5[10]. This test must be used when, in special cases with the approval of the Certification Authority, a geogrid is to be used under particular conditions at a pH > 9.

4.3.4 Aging under the influence of tensile forces: Creep-rupture tests at higher temperatures under the influence of media

To test the aging behavior under the influence of tensile forces, creep-rupture tests are carried out based on DIN EN ISO 13431. Such tests are required if mechanical stress has, or could have, significant effects on the aging behavior. If such effects occur only in the area of the junctions, it is sufficient to conduct appropriate tests on the junctions, see here Section 4.3.5.

Tests are performed on longitudinal and, if necessary, also transverse elements, in both cases with junctions. The degrees of utilization of the maximum tensile strength are selected so that from the total of twelve individual tests at least 3 times to failure of between 10 h and 100 h, 100 h and 1,000 h, 1,000 h and 10,000 h, as well as greater than 10,000 h are achieved. The creep-rupture curve must be determined for at least 3 temperatures in a medium relevant for the aging process. The ISO/TR 20432 standard must be taken into account in determining the creep-rupture curve and its extrapolation to the application temperature. The reduction factor A_4 results from comparison with the creep-rupture curve extrapolated from tests at the application temperature according to DIN EN ISO 13431.

4.3.5 Properties and long-term behavior of the junctions

The geogrid junctions can be formed in different ways. The type and extent of the aging tests is decided on a case-by-case basis. Aging tests are usually required when force transfer in the area of the junctions is not purely by friction between the intersecting elements. As there is very little experience to date with aging tests on junctions, only preliminary requirements with regard to the test procedure and evaluation can be made here.

The behavior of the junctions of drawn and strip geogrids can be determined in tensile tests based on GRI GG2[11]. The load-extension diagram and the failure mode must be documented for at least 20 individual samples (see Table 2 No. 2.8).

In laboratory tensile testing the transverse members are clamped, but the actual junction itself is free. In the application situation the junctions are embedded under load. The tensile properties of the junction embedded in soil under compressive stress will differ from those of a junction in a tensile test in the laboratory. Thus the tensile properties in soil cannot be determined from laboratory tests.

Durability investigations can be undertaken in steps. First, the durability of the junctions can be determined in immersion tests without mechanical stressing. The selection of the test medium and the test conditions depend on the material and the relevant aging processes. The test pieces must be mounted stress-free in a bracket which on the one hand fixes the shape but on the other hand does not impede the influence of the test liquid. The testing of maximum tensile strength based on GRI GG2 is made on at least ten individual samples per withdrawal (see Table 2 No. 2.8). For PET geogrids, the samples are stored for at least one year at 60 °C based on DIN EN 12447. Four withdrawals are made at regular intervals. The reduction in the relative maximum tensile strength should be not greater than 25 %.

For polyolefins, a 28-day autoclave aging test under elevated oxygen pressure in accordance with DIN EN ISO 13438 procedure C is performed[12]. The reduction in the relative maximum tensile strength should be not greater than 25 %.

In the second step the aging behavior of junctions under the influence of a tensile force based on DIN EN ISO 13431 at elevated temperature must be investigated, see Section 4.3.4. The force is exerted

[10] Schröder, H. F.: Ermittlung des Einflusses der alkalischen Hydrolyse auf die Langzeitbeständigkeit von hochfesten Polyester (PET)-Garnen für Geotextilien (Determination of the influence of alkalitic hydrolysis on the long-term durability of high-tenacity polyester (PET) yarns for geotextiles). Fraunhofer IRB Verlag, 1999.

[11] Kupec, J., McGown, A. and Ruiken, A.: Junction Strength Testing for Geogrids. In: Proceedings of the Third European Geosynthetic Conference. Floss, R., Bräu, G., Nußbaumer, M. and Laackmann, K. (Ed.), DGGT and TUM-ZG, Munich, 2004.

[12] Note to the translation: It has been found that the tests at very high pressure are not appropriate to evaluate oxidative resistance. Therefore pressure has be reduced considerably and testing time to be extended accordingly.

on the junctions via a device based on GRI GG2. The selection of the test media depends on the relevant aging mechanisms. Products made of polyester must be tested in water, those made of polyolefins in water and in air. Creep-rupture curves must be determined, initially at at least one test temperature (e.g. 60° C for polyester products and 80° C for polyolefins) and different load levels. The ISO/TR 20432 standard must be taken into account in determining the creep-rupture curve and its extrapolation to the application temperature. From the reciprocal of the degree of utilization for the maximum tensile force of the junction for a period of 100 years at a temperature of, for example, 20° C, an indication of the reduction of the junction strength could in principle be determined from such tests.

Analog test procedures still need to be developed for Raschel knit or woven geogrids.

A third stage may be required depending on the extent of the deviation of the behavior of the junctions from that of the longitudinal and transverse elements. The forces which can be transmitted from the transverse to the longitudinal elements in embedded junctions can be expected to be greater than would be expected from the short-term tensile strength of the free junction. In a third step, therefore, creep-rupture tests based on DIN EN ISO 256191 could be carried out in addition to the above tests on durability and the creep-rupture behavior of "free" junctions to examine this effect.

For this purpose, a shear force of the order of the short-term shear strength together with a pressure force would be applied to the area of the junction in a special test yet to be developed. For PET geogrids, the samples thus loaded would be stored for at least one year at 60° C as described in DIN EN 12447. For polyolefin geogrids, the samples thus loaded would be stored at 80° C for at least one year in air in a well ventilated state. If these conditions lead to failure, the last step would be the determination of creep-rupture curves. Creep-rupture curves at at least three different test temperatures (e.g. 80° C, 70° C and 60° C) would be measured. The ISO/TR 20432 standard must be taken into account in determining the creep-rupture curve and its extrapolation to the application temperature. From the reciprocal of the degree of utilization for the junction strength for a period of 100 years at a temperature of, for example, 20° C, the reduction coefficient for the junction strength can be determined. The reduction coefficient depends on the service life and the temperature.

4.4. Determination of the friction parameters and the pullout resistance

The parameters for the friction between geogrid and geosynthetics, and between geogrid and soil for the failure mechanism "sliding/shearing" (see EBGEO, section 2.2.4.11) are determined in shear-box tests based on DIN EN ISO 129571. The notes in the GDA recommendation E 38 must be observed here. The method used to determine the friction parameters, and representative data and test results for geosynthetics and soil to be used in planning and design calculations, must be presented to the Certification Authority.

The assumption that these friction parameters do not change over time is justified only if the frictional resistance is actually generated by friction between the soil particles or geosynthetic surfaces and surfaces of the grid elements in their contact area. Initially, aging processes will adversely change only the strength properties. Only at a very advanced stage would the surface properties also change to an extent that would affect the friction.

For the planning and design of anchors, the pullout resistance as a function of soil type, superimposed load, and anchorage length must be known. In the interaction between geogrid and soil during pullout, a mechanism of contact friction is in operation between the soil and the elements of the geogrid, as well as an additional mechanism resulting from the interlocking of the soil in the openings of the geogrid[13]. If the geogrid is subjected to tensile load, the transverse elements brace themselves against the soil body in front of them, generating a resistance to displacement. Thus a mechanical loading of the transverse elements results from the passive earth pressure mobilized by the displacement of these elements. The force resulting from the soil resistance,

[13] Jewell, R. A., Soil reinforcement with geotextiles, Thomas Telford, London, 1996.

and the frictional force in the contact zone between the surface of the transverse elements and the soil, are transmitted through the junctions to the longitudinal elements. For a given soil and superimposed load, the pullout resistance of a geogrid is then determined by the following geogrid properties[14]:

- the deformation behavior and the limits on loading of the longitudinal and transverse elements when these are stressed by pullout from the soil,
- the surface friction in the contact zone of grid elements and soil,
- the mechanical stressing of a junction as a function of the displacement of the transverse elements and the related displacement of the junctions for different soils and vertical stresses,
- the failure limit of the junctions under the mechanical stressing resulting from pullout from the soil.

In order to assess what pullout resistance a geogrid can indeed develop long-term under the given conditions, the two last points require further research[15].

An exception to this are products in which the soil resistance transmitted via the transverse elements and junctions and by the friction between transverse elements and soil contributes only marginally to the pullout resistance, i.e. in which soil-geogrid interaction is essentially determined by the friction between the surface of the longitudinal elements and the soil particles. The pullout resistance of such geogrids can be characterized by an interaction coefficient according to the EBGEO method. However, only the interaction coefficient resulting from the purely surface frictional resistance of the longitudinal elements may be used. Furthermore, it must be ensured that the behavior of transverse elements and junctions during pullout does not affect the long-term strength of the longitudinal elements. Appropriate pullout tests only on longitudinal members are then required for the determination of the interaction coefficient.

For all other geogrids, the relationship must be determined between the tensile stress transmitted at a junction and the displacement of the junction, and the failure limits of the junction for a certain range of typical soils and superimposed loads[16.] This applies equally to extruded geogrids because, regardless of the structure of the junctions, the junction zone exhibits a different material behavior to that of the longitudinal and transverse segments and/or because it is always stressed in a particular way. From this, the maximum anchorable tensile force and the minimum required anchor length must be specified. To date there has been little research in this direction. The Certification procedure is breaking new ground here, and the provisions are therefore only preliminary.

The following approach can be adopted in principle: Firstly, both pullout tests (see below) are conducted on specially prepared samples of the respective geogrid with one transverse element with intact junctions, and also tests under identical experimental conditions on the geogrid with disconnected junctions or specially removed transverse segments. The pullout resistance is applied as a function of junction displacement, which is measured either directly or calculated from the deformation behavior of the geogrid. The difference in pullout resistance in the tests with and without transverse element represents the share of the tensile force transmitted by the junction. In this manner, the maximum pullout resistance is determined for different soils and superimposed loads and the behavior of the junctions of a single transverse element under different loads is characterized. The range of typical fill soils and superimposed load is also established for which the shear strength of the soil is sufficient to cause failure of the junctions. For these soils and superimposed loads, pullout tests are then carried out on samples with 2, 3 etc. transverse elements. This leads to the pullout resistances at the limit state of junction failure as a function of the anchorage length. Even if in

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[14] Ziegler, M., Timmers, V.: A New Approach to Design Geogrid Reinforcement. In: Proceedings of the Third European Geosynthetic Conference. Floss, R., Bräu, G., Nußbaumer, M. and Laackmann, K. (Ed.), DGGT and TUM-ZG, Munich, 2004.

[15] Müller, W.: Zur Bemessung der Verankerung von Bewehrungsgittern aus Kunststoff beim Schutz von Böschungen vor hangparallelem Gleiten. Bautechnik 88(2011), H. 6, pp 347 – 352. Müller, W.W., 2014. Long-term pull-out resistance and materials properties of geogrids, in: Ziegler, M., Bräu, G., Heerten, G., Laackmann, K. (Eds.), Proceedings of the 10th International Conference on Geosynthetics. German Geotechnical Society (DGGT), Essen, Germany.

[16] **Note to the translation**: For a more detailed discussion of the following, see references in footnote 16 and 17.

certain cases the test series has to be terminated because the longitudinal elements fail, it should nevertheless be possible to extrapolate the anchor length which can be activated, and the corresponding maximum pullout resistance at the limit state of junction failure.

A similar test program could also be performed with pullout tests on intact samples from the geogrid, in which, in addition to the forces, the displacements at the junctions were measured with transducers under different superimposed load and with different soils. In such tests according to DIN EN 13738 the maximum transmitted tensile stress, the corresponding displacement, the activated anchor length and the pullout resistance of the geogrid can all be directly determined. In this case too, the failure mechanism and the failure pattern must be exactly described. Then, from this, the maximum pullout resistance at the limit state of junction failure and the corresponding activated anchor length can also be determined.

A reduction in the material resistance of the junction in soil must be derived from the evaluation of the behavior of the junctions in aging tests (immersion test and tensile creep-rupture test). In practice, this boils down to the determination of a reduction factor for the maximum pullout resistance at the limit state. This enables the determination of a characteristic value of the maximum pullout resistance, or of the "anchorable" tensile force, as well as the minimum required anchor length in accordance with a yet-to-be-determined test method. These values will to some extent depend on the fill soil and the superimposed load. The behavior and the condition of the anchored geogrid at the thus "semi-empirically" determined maximum pullout resistance should be checked in realistic pullout tests according to DIN EN 13738.

On this basis, limits for the allowable stressing of the anchored geogrids as a function of the soil and the superimposed load are specified in the Certification Document.

Every design calculation must strictly observe this limit, which is set by the still permissible pullout resistance of a geogrid. Design methods which take account of the specific behavior of synthetic geogrids require further development before they are fit for regular use. In currently valid design methods the pullout resistance is calculated in the usual way using the interaction coefficient λ. It must however be noted that the allowable pullout resistance may not be exceeded in any part of the structure.

The interaction coefficient λ is determined in pullout tests (see EBGEO, section 2.2.4.11). The tests can be carried out in the pullout box based DIN EN 13738, and to a certain extent on DIN 60009. The following test conditions apply. A typical soil type should be selected, e.g. well graded sandy gravels. The superimposed load should be at least 20 kPa, 40 kPa and 60 kPa. For application in supporting structures, tests at even higher normal stresses are also required. The sample width should be at least 20 cm, and comprise at least four longitudinal elements. The direction of pullout is always the direction of the load-bearing longitudinal elements (production direction, or machine direction (MD)). The condition of the test samples must be exactly described after the pullout test.

4.5. Environmental compatibility of additives and processing aids

Leachable or water-soluble additives and processing aids must be environmentally friendly. This must be demonstrated in accordance with the procedure given in the FGSV leaflet, Section 6.28[17].

5. In-House[18] and Third-Party Production Quality Control

Annex 1 number 2.1 of the Landfill Ordinance requires that the uniform quality of the production of the pre-products and the geogrids must be ensured by regular in-house and third-party inspection. These activities must be incorporated in a quality-management

[17] Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaues mit den Checklisten für die Anwendung von Geokunststoffen im Erdbau des Straßenbaues (C Geok E).
Note on the application of geosynthetics in road-construction earthworks with checklists for the application of geosynthetics in road-construction earthworks FGSV-Verlag, Cologne, 2005.

[18] In the construction industry (Construction Products Directive), in-house quality control is now termed factory production control (FPC).

system certified in accordance with DIN EN ISO 9001.

As a matter of principle, the in-house QC or "the system of factory production control" in the production of the geogrid must comply with the requirements of DIN EN 13257 Section 5.4 and Annex A.

The valid certification document, the organigram detailing responsibilities, and the manufacturer's quality-management manual including testing schedules must be submitted to the Certification Authority.

The type and extent of identification checks and controls of purchased or self-produced pre-products is regulated in the Certification Document on a case-to-case basis. Table 5 describes the type and extent of in-house QC and third-party inspection in the production of the geogrid, and the minimum extent of testing. The type and frequency of testing must be agreed with the certifying body and described in the Annex to the Certificate of Approval.

5.1. Pre-product controls and tests

The manufacturer must check that the resins and additives – e.g. the base polymer and the additive batches – used in the elements of the geogrid are the same as the materials used in the production of test samples for the Certification procedure. The type and frequency of the incoming QC tests required of the geogrid manufacturer are stipulated based on Table 1 in the Certification Document.

If the manufacturer of the geogrid is also the manufacturer of the grid elements, no incoming QC inspection of these pre-products is required. In such cases, however, quality assurance of the production of the elements must be carried out with appropriate in-house quality control. The type and frequency of the tests required of the geogrid manufacturer are stipulated based on Table 1 in the Annexes to the Certification Document.

5.2. In-house production quality control

As part of the in-house manufacturing QC of the geogrid, specific characteristic properties of the products must be checked. Table 5 describes procedures and specifies frequencies with which checking must be performed. The type and frequency of the tests required of the geogrid manufacturer are stipulated based on Table 5 in the Annex to the Certification Document. Here, the product-related requirements and tolerances specified in the Certification Document must be fulfilled.

The test data must be archived for 10 years so as to provide traceability of the test results for any given delivered unit. This test data must be made available to the Certification Authority upon demand.

An acceptance test certificate 3.1 must be issued for each shipment on the basis of DIN EN 10204. The test values in the acceptance test certificate must be able to be assigned to the delivery units on which they were measured. The acceptance test certificate must contain a statement that the production has used the materials and pre-products declared in the documents confidentially deposited with the Certification Authority.

5.3. Third-party inspection of the production

Production of the geogrid must be subject to inspection by a neutral third-party institute approved by BAM (see Section 11). The institute charged with the third-party inspection must have sufficient testing and inspection personnel and the necessary test equipment to fulfill the requirements of DIN EN ISO/IEC 17025 or DIN EN ISO/IEC 17020 and be approved by the Certification Authority as a third-party inspector. A prerequisite for this approval is accreditation for the standard tests conducted in third-party inspection. Tests for which the testing and inspection body is not accredited may be carried out by an accredited laboratory as a subcontractor. The valid inspection contract between manufacturer and inspection agency must be submitted to BAM.

The inspection includes a check of the input controls of pre-products, inspection of the pre-products and validation of their shipping documents, the testing of the properties of the geogrid as well as the checks on its production and the inspection of factory production control. With respect to the inspection, DIN 18200 and the inspection contract are authoritative documents. The inspection contract must take the following requirements into account:

- At the start of production, the third-party inspector must satisfy himself that the prerequisites for proper manufacturing and in-house QC are fulfilled.
- In the third-party inspection of the production of the geogrid the tests listed in the Annex to the Certification Document on the properties of the pre-products and the geogrid must be performed (see Table 5). During the inspection visit, the laboratory and production must be visited and the records examined to monitor the type and extent of the controls on incoming pre-products and the in-house factory production control.
- The third-party inspection must be carried out twice per year. The material samples for the tests must be taken by the third-party inspector directly from production. When monitoring a product family, one product of the family must be verified in each third-party inspection. The third-party inspector selects the product in accordance with production planning. He should ensure that different products are included in the inspection.

The inspection visits must normally be unannounced. Proof that third-party inspection has been carried out is confirmed by the inspection report, in which the third party inspector presents its test results. Results from the tests performed by the third-party inspector in connection with a third-party inspection on site, see Table 6, must be included in the audit report. The report is sent to the manufacturer being inspected on a regular basis.
In the event that defects are discovered, the third-party inspection institute will decide what measures must be taken. Should repeated or serious deficiencies be discovered, the inspection institute must inform BAM accordingly.

5.4. Shipping documents

The requirements of in-house and third-party inspection also dictate the requirements on the type and extent of the papers which must be included with a shipment of the geogrid to document its quality. A delivery note with details of the manufacturer, the product-type designation, a list of roll numbers and dimensions is required. This then includes an in-house QC acceptance test certificate for the geogrid based on DIN EN 10204. The third-party inspection certificate and the full Certification Document must be available on the site; in its annex this document contains the requirements for in-house and third-party inspection, and the transport, storage and installation instructions.

6. Installation Requirements

The state of the art does not apply solely to the production and properties of the certified geosynthetics. According to Annex 1 No. 2.1.1 of the DepV, the installation of the components in the sealing system must also comply with the state of the art. Therefore, the compliance with the following installation requirements is a prerequisite for the applicability of the certification as proof of the suitability of a geomembrane. This section 6 is therefore authoritative for the waste-legislative acceptance according to clause 5 of the DepV.
In all other cases, installation personnel must be trained in advance by a qualified specialist. This includes an introduction to dealing with the installation drawings, to the type and handling of transportation devices, to the installation technique, to the design of longitudinal jointing and anchoring in anchor trenches, to the requirements of the quality-assurance plan and sampling for on-site inspection measures and finally to the handling of the devices and the procedure for the placing further layers over geogrids already laid. Content, participants, time and duration of the training must be documented and be checked by the on-site third-party inspector.

6.1. Notes on the installation procedure

The manufacturer’s instructions on transport, storage and installation must be observed. Additional information on the installation procedure can be found in EBGEO.
Structures in which the tensile forces between geogrids are transmitted via seams or joints, or by tying the geogrid into the structure, are not permitted.
The geotextile must be covered at the end of each working day if possible, but no later than one week after installation.
At points where the slope inclination changes, the

geogrid exerts a downward normal force on its support, which can result in compressive strain in e.g. a geocomposite drain installed under the geogrid. Such zones occur for example in the transition to berms or at the embankment crown. The water discharge capacity of the geocomposite drain must then be ensured by constructive measures, e.g. by bridging with a piece of drainage composite above the geogrid with adequate overlap.

6.2. Stressing caused by Installation and construction operations

The installation and the compaction of the soils and the drainage layer as well as the fill soil in the anchorage lead to particular stressing of the geogrid. For some materials, damage to the geogrid has only a minor effect on its long-term behavior. For materials sensitive to stress-cracking (e.g. HDPE), even slight damage to the geogrid, such as notches or grooves, can have a drastic effect on its long-term tensile strength. This applies also to coated geogrids if the coating significantly contributes to the chemical resistance.

As a matter of principle, the installation procedure should be optimized so that damage to the geogrid is kept to a minimum. In particular, the geogrid may not be directly trafficked. The first layer of material must be placed by front-dumping, and then distributed without sliding the material over the geogrid; it should then be compacted.

Additional site trials are always required in particular cases if the site conditions deviate from those in the tests previously carried out (aggregates, method and degree of compaction, formation layer etc.). Since the stressing in landfill construction is usually lower than the stressing described in EBGEO (installation testing for level geosynthetic layers), the test conditions can be modified accordingly. The Annex (Section 12) gives additional suggestions for site trials.

6.3. Quality management

The geogrids are part of the landfill-liner system. Their installation is therefore regulated by the quality-management measures required in the DepV. The DepV foresees a three-part system of quality management in which the self-inspection of the installer responsible for the quality of his work, the third-party testing by an independent on-site third party inspector, and the monitoring by the responsible authority ensure that the landfill-liner system is constructed with the designed quality characteristics (see here also the GDA recommendation E 5-5 "Quality Monitoring for Geosynthetics")

The quality-management measures are based on the quality-management plan, which must include the installation of the geogrids. Quality-assurance plans are an integral part of the quality-management plan for the auditing of the individual components of the sealing system. In establishing the quality-assurance plan for the geogrids and in their installation as well as in the related verification tests, the terms and conditions of the Certification Document and the transport, storage and installation instructions specified in the Annex to the Certification Document for the geotextiles must be observed. Quality control plans, in which the verification tests on the individual components of the seal are described, have to be part of the quality management plan. A sample of standards for the quality control plans can be found on the BAM internet site[19]

The preparation of an installation plan is one of the features of the quality-management measures. Unambiguous information on the location and type of the geogrids placed must be included in the final installation plan.

Third-party inspection must be carried out by a qualified and experienced institute with adequate personnel and equipment. The requirements that must be fulfilled with regard to the qualifications and duties of the on-site third-party inspector are described in the BAM Guidelines for on-site Third-Party Inspection. The third-party inspector and the extent of his duties must be agreed with the responsible approval authorities. The costs of third-part inspection are borne by the Landfill Operator. The third-party inspector works closely with the responsible authority. The type and extent of tests on geogrids within the scope of third-party inspection are listed in Table 6.

[19] http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm

7. Notes on Design

Verification of stability is made in accordance with the rules of GDA recommendation E 2-7 and EBGEO. The design rules and calculations used in the main application of geogrids are described in Section 8, "Landfill construction - Reinforcement of surface-parallel stratified systems" of EBGEO. The required long-term strength of the geogrid is given by:

$$R_{B,k} = R_{B,d} \cdot \gamma_M \cdot \eta_M \, .$$

Here, $R_{B,d}$ is the design strength of the reinforcement determined from the equilibrium equation in the ultimate limit state, γ_M the load-case-dependent partial safety coefficient of material resistance and η_M is an additional load-dependent correction factor. The relationship between the design strength of the reinforcement $R_{B,d}$ and the short-term strength of the geogrid $R_{B,k0}$ is then given by the following equation of EBGEO:

$$R_{B,d} = \frac{R_{B,k0}}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \gamma_M \cdot \eta_M} \, .$$

In calculating the design values, the characteristic values of the relevant properties of the geogrid and the reduction factors can be taken from the Certification Document.

Supplementing the rules of EBGEO, the following boundary conditions must be observed, with which the problem of the long-term behavior of the junctions is to be taken into account. The Certification Document stipulates the interaction coefficient for frictional grids (see Section 3), with which the pullout resistance can be calculated. For all other geogrids a maximum pullout resistance is indicated which must not be exceeded, and a minimum anchor length which must be achieved.

The design of anchorages or retaining structures is described in EBGEO. Here too, the stressing limits specified in the Certification Document have to be observed. Here, in addition, it must be explicitly verified in the design using conventional methods that for any possible slip surface and for each affected reinforcement layer, the characteristic value of the required pullout resistance derived from the soil-mechanical calculation does not exceed the permissible value of the pullout resistance and that the required anchorage length is exceeded. The value of the maximum pullout resistance according to the Certification Document then determines the practicable permissible degree of utilization of the short-term resistance of the geogrid.

8. Changes, Notification of Defects and Period of Validity

Changes to the object certified, i.e. the materials, the pre-products, the geogrids themselves, the dimensions, the production process, the installation procedure, the production plant, or the intended use, require a new Certificate or a supplement thereto. If the requirements, terms, and conditions of approval are violated in the production, transportation or installation, the geogrid thus manufactured and placed is considered as not suitable for purpose and not certified. The third-party production and on-site inspector and/or the authorities responsible for approving installation must report to BAM any repeated and serious deficiencies discovered in the manufacture and installation of the geogrids, and any failures of landfill-liner systems associated with the object certified.

9. Requirement Tables

Table 1 **Characteristic properties of the pre-products (extruded sheets or flat rods, filaments, multifilament yarns etc.)[1]**

No.	Property	Requirement	Test method
1.1	Type of pre-product	Exact description of the type of pre-product, the materials, the coating, dimensions, production processes, draw ratio, treatment or post-treatment, etc.	-
1.2	Melt mass-flow rate	Manufacturer's specification	DIN EN ISO 1133
1.3	Density	Manufacturer's specification	DIN EN ISO 1183-1
1.4	Enthalpy of fusion and Melting point: Glass-transition temperature	Manufacturer's specification	ISO 11357-3
1.5	Maximum tensile strength	Manufacturer's specification	DIN EN ISO 5079 or in-house procedure
1.6	Elongation at Maximum tensile strength	Manufacturer's specification	DIN EN ISO 5079 or in-house procedure
1.7	E-Modulus	Manufacturer's specification	DIN EN ISO 5079 or in-house procedure
1.8	OIT	Manufacturer's specification	ISO 11357-6
1.9	Stabilizer content[2]	Manufacturer's specification	Solid/liquid extraction - UV Spectroscopy or HPLC Analysis on the extract[2].
1.10	Carbon black content	Manufacturer's specification	Thermogravimetric analysis based on DIN EN ISO 11358 or determination in accordance with ASTM D 1603-06.
1.11	Content of carboxyl end groups	Manufacturer's specification	Based on GRI GG7 and ASTM D 7409 or in-house procedure[2]
1.12	Content of polyethylene glycol	Manufacturer's specification	In-house procedure
1.13	Limit-viscosity number	Manufacturer's specification	GRI GG8
1.14	Stress-cracking resistance	Platens or extruded plates made from the material of the geogrid, 2 mm thick, time to failure ≥ 400 h	ASTM D 5397; 10 % surfactant solution (Arkopal N 150)

1) The choice of the required tests depends on the materials and types of the pre-products. Test requirements and in-house procedures are usually confidential to the manufacturer, and are treated as such when given to the Certification Authority.

2) Additional information and explanations on the tests can be found on the website http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

Table 2a: **Characteristic properties of geogrids**

No.	Property	Requirement	Test method
2.1	Type of geogrid	Exact description, e.g. type of geogrid, geometry and associated dimensions, type of junctions and their production, processing aids, roll length and weight, etc.	-
2.2	Mass per unit area	Manufacturer's specification	DIN EN ISO 9864
2.3	Geometry	Manufacturer's specification	In-house procedure
2.4	Tensile strength (MD and CMD)[1]	Manufacturer's specification	DIN EN ISO 10319
2.5	Elongation at max. tensile strength (MD and CMD)	Manufacturer's specification	DIN EN ISO 10319
2.6	Tensile strength per unit width at 2 % elongation (MD)	Manufacturer's specification	DIN EN ISO 10319
2.7	Tensile strength per unit width at 5 % elongation (MD)	Manufacturer's specification	DIN EN ISO 10319
2.8	Quality of the junctions (MD)	Manufacturer's specification	Based on GRI-GG2; sample preparation DIN EN ISO 9862; at least 20 test pieces; crosshead speed 50 mm/min; documentation of the load/extension diagrams and exact description of damage.
2.9	Tensile creep behavior (Isochrone curves)	Required for the assessment of fitness for purpose.	DIN EN ISO 13431
2.10	Creep-rupture behavior (times to failure for ductile failure)	Required for the determination of A_1.	DIN EN ISO 13431
2.11	Tensile-creep and creep-rupture behavior, Stepped Isothermal Method (SIM)	Required for the assessment of the fitness for purpose and determination of A_1.	ASTM D 6992

MD: machines and/or production direction; CMD: direction normal to machine and/or production direction

1) The following applies according to DIN EN 13257, Annex ZA, Note 1: “A test in one direction only may be sufficient for some products; in this case this should be clearly stated in the information accompanying the CE marking."

Table 2b: **Interaction between geogrid and soil**

2.12	Friction parameters	Manufacturer's specification	DIN EN ISO 12957-1
2.13	Interaction coefficient	Manufacturer's specification	DIN EN 13738: 2005 DIN 60009: 2008
2.14	Installation damage in field trials	Stipulation of reduction factor A_2.	EBGEO, Section 2.2.4.6.3 and notes on the tests[1]

1) Additional information and explanations on the tests can be found on the Internet page of BAM at http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

Table 3: **Basic checks on the resistance of polymeric geogrids within the scope of CE marking (according to DIN EN 13257, boundary condition: 25 years expected service life, environment pH 4 – 9, temperature ≤ 25° C)**

No.	Resistance	Test standard	Remarks
3.1	Oxidation (polyolefins)	DIN EN ISO 13438	Requirements are set in DIN EN 13257 depending on the raw material.
3.2	Hydrolysis (PET and PA)	DIN EN 12447: 2005	
3.3	Weathering resistance	DIN EN 12224: 2005	Requirement = high weathering resistance (deviates from DIN EN 13257 in that here only a maximum exposure time of < 7 days is permissible)

Tests and requirements on products made of other materials (such as PVA, etc.) are set based on the procedure referred to in the table. In individual cases, a decision is made on whether the tests on a representative product can be used as a proxy for a product family.

Table 4: **Requirements on durability and long-term performance of synthetic geogrids[1.2]**

No.	Property	Test Attribute	Requirement	Test/Test Conditions
4.1	Oxidative degradation in air, e.g. for polyolefins	Change in external appearance	no pronounced change	Air-oven aging based on DIN EN 13438 in a forced air oven (s. ISO 188, 4.1.4); storage temperature 80° C; Storage period 1 year Storage of samples from which at least 5 test pieces for the tensile tests can be punched out; sampling and tensile test based on DIN EN 12226; Analytical methods for the measurement of change in stabilization; DSC for measurement of crystallinity.
		Relative change in crystallinity n	$\delta n \leq 10$ %	
		Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max}	$\delta T_{max} \leq 20$ % $\delta \varepsilon_{max} \leq 20$ %, where appropriate, determination of the reduction factor A_4	
		Relative change in the mass fraction of antioxidants c_S	$\delta c_S \leq 50$ %	
4.2	Leaching and oxidative aging, e.g. of polyolefins	Change in external appearance	no pronounced changes	Hot-water storage based on DIN EN 14415; water temperature 80° C; storage period 1 year; Storage of elements with junctions for tensile testing; Sampling and tensile tests based on DIN EN 12226; Analytical method for measurement of change in stabilization. DSC for measurement of crystallinity.
		Relative change in crystallinity n	$\delta n \leq 10$ %	
		Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max}	$\delta T_{max} \leq 20$ % $\delta \varepsilon_{max} \leq 20$ %, where appropriate, determination of the reduction factor A_4	
		Relative change[2] in the mass fraction of antioxidants c_S	$\delta c_S \leq 50$ %	
4.3	Resistance to oxidative aging (autoclave test)[3], e.g. for polyolefins	Change in external appearance	Assessment of expected service life under conditions of use according to the procedure of Schröder et al. (2008)[3]; Verification of service life ≥ 100 years, where appropriate, determination of reduction factor A_4	Hot-water storage in high-pressure autoclave under elevated oxygen pressure based on DIN EN ISO 13438, Proof C; storage temperatures 60° C, 70° C, 80° C, pH 10, oxygen pressures 1 MPa, 2 MPa, 5 MPa; samples stored until a residual strength of 50 % is reached; Tensile test and sampling see DIN EN 12226; Analytical methods for measurement of change in stabilizer content; DSC for measurement of crystallinity.
		Relative change in crystallinity n		
		Relative change in mean values of tensile strength T_{max} and elongation at tensile strength ε_{max}		
		Relative change in mass fraction of antioxidants c_S		
4.4	Hydrolysis in water (internal hydrolysis), e.g. for polyester	Change in external appearance	no pronounced change	Hot-water storage based on DIN EN 12447; at least four temperatures (e.g. 55° C, 65° C, 75° C, 85° C); storage time: at least one year; Storage of elements with junctions for tensile testing; Sampling and tensile tests based on DIN EN 12226; Analytical methods for the determination of the carboxyl end-group content or the solution viscosity; DSC to measure crystallinity and glass-transition temperature.
		Relative change of crystallinity n and of glass-transition temperature	$\delta n \leq 10$ %	
		Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max}	Life-expectancy extrapolation, determination of reduction factor A_4	
		Relative change of mean molecular weight δN and glass-transition temperature	Extrapolation in Arrhenius diagram: $\delta N \leq 50$ %	

1) Tests and requirements on products made of other materials are set based on the procedure referred to in the table. In individual cases, a decision is made on whether the tests on a product can be used as a proxy for a product family.

2) Additional information and explanations on the tests can be found on the Internet page of BAM at http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

3) Schröder, H. F., Munz, M. und Böhning, M.: A New Method for Testing and Evaluating the Long-Time Resistance to Oxidation of Polyolefinic Products. Polymers & Polymer Composites, 16(2008), H. 1, pp 71-80. **Note to the translation**: Meanwhile research has clearly indicated that reliable results which map the aging behavior under usual condition can only be achieved with test pressures well below 0.5 MPa.

Table 4: **Continued: Requirements on durability and long-term performance of synthetic geogrids**

No.	Property	Test Attribute	Requirement	Test/Test Conditions
4.5	Hydrolysis in water (external hydrolysis), e.g. for polyesters	Change in external appearance	no pronounced change	hot-water storage in alkaline medium based on DIN EN 12447; gypsum suspension, hydroxyl-ion concentration: 5×10^{-4} mol/l (corresponds to pH 11 at 20° C); storage temperature: 60° C; Storage time: at least one year and a minimum of 4 withdrawals. Storage of samples, from which at least 5 test pieces for the tensile tests can be punched out. Tensile test and sampling according to DIN EN 12226. Analytical methods for the determination of the carboxyl end-group content or the solution viscosity; DSC to measure crystallinity and glass-transition temperature.
		Relative change in crystallinity n and in glass-transition temperature	$\delta n \leq 10$ %	
		Relative change in mean values of tensile strength T_{max} and elongation at tensile strength ε_{max}	Life-expectancy extrapolation, Determination of reduction factor A_4	
		Relative change in mean molecular weight δN	$\delta N \leq 50$ %	
4.6	Long-term behavior under combined stressing	Creep-rupture behavior, creep-rupture curves	Service-life extrapolation, determination of reduction factor A_4	DIN EN ISO 13431 in connection with ISO/TR 20432
4.8	Aging in the node area, internal hydrolysis	Relative change in junction strength	≤ 25 %	Hot-water storage based on DIN EN 14415; water temperature: 60° C; storage time: at least one year; Storage of elements with junctions for testing according to GRI GG2; sampling and preparation according to DIN EN ISO 9862. Form-fixing sample holders and stress-free installation; at least 4 withdrawals, each with 10 individual samples. Documentation of the load/extension diagrams and of damage images.
4.9	Creep-rupture tests on junction behavior	Creep-rupture behavior, creep-rupture curves	Still to be set	DIN EN ISO 13431 in conjunction with ISO/TR 20432. Tensile creep-rupture tests on junctions with clamps based on GRI GG2. Determination of the creep-rupture curve. 12 load levels, 3 samples per load level. Test temperature: 60° C for polyester, 80° C for polyolefins.

Table 5: **Nature and extent of in-house and third-party inspection (IHI and TPI) in the production of the geogrid and check testing on pre-products.**

No.	Property	Test method	Necessity		Minimum extent in the IHI
			IHI	TPI	
5.1	Identification and check testing on pre-products[1]	see Certification Document	X	X[2]	see Certification Document
5.2	Tensile strength (MD)[3]	DIN EN ISO 10319	X	X	at least every 3000 m²
5.3	Elongation at tensile strength (MD)	DIN EN ISO 10319	X	X	at least every 3000 m²
5.4	Tensile force per sample width at 2% elongation	DIN EN ISO 10319	X	X	at least every 3000 m²
5.5	Tensile force per sample width at 5 % elongation	DIN EN ISO 10319	X	X	at least every 3000 m²
5.6	Geometry (width of longitudinal and transverse elements, dimensions of the grid openings)	see Footnote 4	X	X	at least every 3000 m²
5.7	Mass per unit area	DIN EN ISO 9864	X	X	at least every 3000 m²
5.8	Quality of junctions (product-dependent)	In-house procedure GRI GG2 etc.	X	X	at least every 3000 m²

1) Depending on the type of geogrid, the Certification Document stipulates which identification and check tests are to be performed on the purchased or self-produced pre-products at the geogrid manufacturer.

2) in the scope of third-party inspection, as a minimum the documentation must be reviewed at the manufacturer. If necessary, the third-party inspector carries out his own checks. The nature and extent are defined in the Certificate of Approval.

3) MD: Production or machine direction.

4) Additional information and explanations on the tests can be found on the BAM website at http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

Table 6: Type and extent of tests on geogrids in the scope of third-party inspection on site[1]

No.	Test Attribute	Test	Frequency
6.1	Tensile strength (MD)	DIN EN ISO 10319	every 5000 m²
6.2	Elongation at tensile strength (MD)	DIN EN ISO 10319	every 5000 m²
6.3	Tensile force per sample width at 2% elongation	DIN EN ISO 10319	every 5000 m²
6.4	Tensile force per sample width at 5 % elongation	DIN EN ISO 10319	every 5000 m²
6.5	Geometry (width of longitudinal and transverse elements, dimensions of the grid openings)	see Footnote 2	every 5000 m²
6.6	Mass per unit area	DIN EN ISO 9864	every 5000 m²
6.7	Quality of junctions	In-house procedure GRI GG2 etc.	once based on the total shipment for the construction phase

1) Third-party inspectors will not always have the technical prerequisites to perform tests on high-strength geogrids according to DIN EN ISO 10319, and the special test in 6.7. In this case, the samples from the site must be tested by the external auditor.

2) Additional information and explanations on the tests can be found on the BAM website at http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

10. List of standards

The currently valid version of the standard.

ASTM D 1603:2006	Standard Test Method for Carbon-Black Content in Olefin Plastics
ASTM D 5397:2012	Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
ASTM D 6992:2016	Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method
ASTM D 7409:2015	Standard Test Method for Carboxyl End Group Content of Polyeth-ylene Terephthalate (PET) Yarns
DIN 18200:2000	Assessment of conformity for construction products - Certification of construction products by certification body – factory production con-trol, third-party inspection and certification of products
DIN 60009:2011	Geosynthetics - Testing and Determination of the Interaction Coef-ficient with Soil in the Pullout Test
DIN EN 10204:2005	Metallic products – Types of inspection documents
DIN EN 12224:2000	Geotextiles and geotextile-related products – Determination of re-sistance to weathering
DIN EN 12226:2012	Geosynthetics - General test methods for assessment after durabil-ity tests
DIN EN 12447:2002	Geotextiles and geotextile-related products – Test methods for de-termining the resistance to hydrolysis in water
DIN EN 13252:2016	Geotextiles and geotextile-related products – required properties for application in drainage systems
DIN EN 13257:2016	Geotextiles and geotextile-related products – required properties for application in the disposal of solid waste
DIN EN 13738:2005	Geotextiles and geotextile-related products - Determination of pullout resistance in soil
DIN EN 14415:2004	Geosynthetic barriers - Test method for determining the resistance to leaching
DIN EN ISO 527-1: 2012	Plastics - Determination of tensile properties
DIN EN ISO 1133-1: 2012	Plastics – Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics
DIN EN ISO 1183-1: 2013	Plastics - Methods for determining the density of non-cellular plas-tics – Part 1: Immersion method, liquid pyknometer method and ti-tration method
DIN EN ISO 5079:1996	Textiles - Fibers - Determination of breaking force and elongation at break of individual fibers
DIN EN ISO 9001:2015	Quality-management systems - Requirements
DIN EN ISO 9862:2005	Geosynthetics - Sampling and preparation of test specimens
DIN EN ISO 9864:2005	Geosynthetics - Test method for determination of the mass per unit area ofgeotextiles and geotextile-related products
DIN EN ISO 10319:2015	Geosynthetics - Wide-width tensile test (ISO 10319:2008)
DIN EN ISO 10320:1999	Geotextiles and geotextile-related products – Identification on site
DIN EN ISO 11358:2014	Plastics – Thermogravimetry (TG) of polymers - General principles
DIN EN ISO 12957-1: 2005	Geosynthetics – Determination of friction properties – Part 1: Shear-box test
DIN EN ISO 13431:1999	Geotextiles and geotextile-related products - Determination of ten-sile creep and creep-rupture behavior
DIN EN ISO 13438:2005	Geotextiles and geotextile-related products - Screening test method for determining the resistance to oxidation
DIN EN ISO 25619-1: 2009	Geosynthetics – Determination of compression behavior - Part 1: Compressive-creep properties
DIN EN ISO/IEC 17020: 2012	Conformity assessment – Requirements for the operation of various types of bodies performing inspection

DIN EN ISO/IEC 17025: 2005	General requirements for the competence of testing and calibration laboratories
GDA E 2-7:2015	Sliding stability of the sealing systems
GDA E 2-9:2005	Application of geotextiles in landfill construction
GDA E 3-8:2015	Determination of shear behavior of combined barrier layers
GDA E 5-5:2010	Quality monitoring for geotextiles
GRI GG2:2012	Geogrid Junction Strength
GRI GG7:2012	Carboxyl end group content of PET Yarns
GRI GG8:2012	Determination of the Number Average Molecular Weight of PET Yarns Based on a Relative Viscosity Value
ISO 11357-3:2011	Plastics - Differential scanning calorimetry (DSC) - Part 3: Determination of melting and crystallization temperature and of the enthalpy of melting and crystallization
ISO 11357-6:2008	Plastics - Differential scanning calorimetry (DSC) - Part 6: Oxidation induction time (isothermal OIT) or temperature (isodynamic OIT)
ISO/TR 20432:2007	Guidelines for determining the long-term strength of geosynthetics for soil reinforcement
ISO/TS 13434:2008	Guidelines on the durability of geotextiles and geotextile-related products

11. Annexes to Certification Document, List of State Codes, Testing and Inspection Bodies

Annex to Certification Document

Annex 1: Requirements and tolerances for in-house and third-party inspection,
Annex 2: Exact designation of the manufacturer with production sites
Annex 3: Description of the production process
Annex 4: Manufacturer's declaration on materials used
Annex 5: Description of construction and arrangement of the marking
Annex 6: Description of location of markings
Annex 7: Description of the roll labels
Annex 8: Description of quality-assurance measures
a) In-house inspection
b) Third-party inspection
Annex 9: Manufacturer's storage and transport instructions

State codes

(from (Bundesarbeitsblatt (Federal Labor Gazette) 4/91, page 61):

Baden-Wurttemberg	01	Lower Saxony	07
Bavaria	02	North Rhine-Westphalia	08
Berlin	03	Rheinland Palatinate	09
Brandenburg	12	Saarland	10
Bremen	04	Saxony	14
Hamburg	05	Saxony-Anhalt	15
Hesse	06	Schleswig-Holstein	11
Mecklenburg-Vorpommern	13	Thuringia	16

Testing and notified bodies for suitability testing and production monitoring

Kiwa TBU GmbH
Gutenbergstr. 29
48268 Greven
Tel.: 02571 9872-0, Fax: 02571 9872-99, email: tbu@tbu-gmbh.de

Materialforschungs- und -prüfanstalt Weimar (MFPA)
Fachgebiet Geotechnik
Coudraystr. 4
99423 Weimar
Tel.: 03643 564-0, Fax: 03643 564-201, email: info@mfpa.de

Materialprüfanstalt für Werkstoffe und Produktionstechnik (MPA) Hannover
An der Universität 2
30823 Garbsen
Tel.: 0511 762-4362, FAX.: 0511 762-3002; email: info@mpa-hannover.de

SKZ – Testing GmbH
Friedrich-Bergius-Ring 22
97076 Würzburg
Tel.: 0931 4104-142, Fax: 0931 4104-273, email: testing@skz.de

12. Annex: Carrying out site trials

So-called "site trials" involve checks on the extent to which the geogrid is damaged during transport, soil placement, and compaction, and how such damage affects the short-term tensile strength of the geogrid. The large-scale field trials described as site trials in Section 2.2.4.6 of EBGEO are also applicable in landfill construction if the following requirements are met. Typically, manufacturers have already carried out a considerable number of such site trials. These trials enable determination of the reduction factor A_2, which must be taken into account in determining the long-term tensile strength. Information regarding this is contained in the Certification. The manufacturer's instructions with regard to transportation must be strictly observed. Additional site trials are always required in particular cases if the site conditions deviate from those in the tests previously carried out (aggregates, method and degree of compaction, formation layer etc.).

The following describes the individual steps in performing a site trial, whether prior to any particular project or in direct connection with a construction project. A few square meters must be cut from the geogrid roll to be examined and put aside as reference samples. At least ten test pieces must be cut from the reference sample for the wide-width tensile test according to DIN EN ISO 10319. These must guarantee a free clamping length of at least 300 mm and there must be at least two complete grid openings in the direction of tensile load within the free test length. The free test length must be specified in the test report. The bearing capacity of the subgrade in the test field must be such that the aggregate can be properly compacted. Site trials for a particular project must utilize the same materials for the subgrade and the aggregate layer as those foreseen for the actual project, and these must be of the same thickness and placed with the same compaction method. In pre-project site trials to determine A_2 for stress situations typical of landfill construction, a 0.25 m thick layer of 0 - 16 mm aggregate in accordance with ZTV SoB-StB[20] can be placed and compacted. Compaction is carried out with a vibro roller or a single-drum compactor with a gross weight of about 10 to 12 t using large-amplitude vibration (approx. 1.5 to 2.0 mm) until a measured degree of compaction of D_{Pr} = 100 % is achieved. Compaction takes place at right angles to the longitudinal elements of the geogrid.

The test report of field and site trials must detail the bearing capacity of the subgrade E_{v2}, the aggregate used, the installation method and equipment, the compactor, the device settings and the number of compaction passes. For sampling the following requirements must be observed. Once the area is established in which the aggregate will be placed and compacted on the geogrid, 10 sections within this area must be clearly marked in which test pieces will subsequently be taken. The size of the marked section must be 10 cm greater than the test piece in each direction. One test piece each may be taken only from the areas so designated. The excavation and the recovery of the samples must be carried out so carefully that no further damage can occur. The tensile tests on the test pieces must be carried out with the same test machine with the same clamps and under the same test conditions as the reference samples. The tensile tests are always performed in the direction of the longitudinal members. All ten test pieces must be tested and the results included in the evaluation. The reduction factor A_2 is then determined as a ratio of the mean values of the tensile strengths of the reference samples and the recovered samples.

[20] FGSV-No. 698: Additional technical conditions of contract and guidelines for the construction of binderless layers in road construction (ZTV SoB-StB 04). FGSV Verlag GmbH, 2004