Guidelines for the Certification of Protection Layers for Geomembranes in Landfill Sealing Systems

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These Certification Guidelines and the list of certified protection layers, as well as additional guidelines for other geosynthetics and third party control based on the Landfill Regulations and lists of products certified under these guidelines, can be downloaded as pdf-files from the internet sites:
www.bam.de/de/service/amtl_mitteilungen/abfallrecht/index.htm
www.bam.de/en/service/amtl_mitteilungen/abfallrecht/index.htm

Foreword

The new Landfill Ordinance (DepV) came into force on 16 July 2009. It was amended in the first Regulation amending the Landfill Ordinance dated 17 October 2011. 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 leak detection 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 in the European Economic Area in accordance with the regulations or requirements in force there, if the properties obtained from the tests and inspections in the country of manufacture guarantee that the material, component and system realize 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 Committee is involved in establishing appropriate Certification guidelines.
After the Landfill Ordinance came into force on October 16, 2009, the Advisory Committee was constituted and established a working group which revised the Certification Guidelines for Protection Layers of August 1995. The result of this work are new Guidelines for the Certification of Protection Layers for Geomembranes in Landfill Sealing Systems. Since then, the fifth edition has been issued.

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1. Introduction

The aim of the Certification of a protection layer for the geomembranes in landfill liner and capping systems on the basis of the Landfill Ordinance (DepV) is to help ensure that the systems used are rated on an identical basis and that only those are used which guarantee long-term, effective protection in accordance with the state of the art[1]. For the base sealing, the DepV requires explicitly that "the sealing components (are) to be protected against load-induced damage" (see Annex 1, No. 2.2). This of course also applies to the cap sealing. However, protection here is easier to achieve.

In accordance with the state of the art it has proved appropriate to differentiate between three different types of protection layers for a Certification procedure (see also DIN 19667):

1. Protection-layer systems consisting of a geotextile protection layer and an additional load-distributing mineral protection layer (combined protection layer). As a rule, the geotextile protection layer consists of a nonwoven fabric with a mass per unit area of at least 1200 g/m². For the granular protection layer, a crushed granular material with a particle size 0 - 8 mm and low lime content is customary. Other mineral materials, such as materials from waste recycling, may be used if their particle-size distribution curves satisfy the requirement of filter stability opposite the drainage layer and they offer adequate protection and long-term resistance.
2. Protection-layer systems of geocontainers filled with sand. Here, sand (particle size 0 - 2 mm) is used as a protection layer, and this is 'packaged' in different ways in geotextiles. Systems partially or wholly pre-fabricated in the factory are utilized (e.g. ready-made sand mattresses, or geotextile containers, which are filled with sand on site).
3. Purely geosynthetic protection layers using nonwovens or composites of wovens, geogrids or other geosynthetics.

[1] See Werner Müller, HDPE Geomembranes in Geotechnics. Springer Verlag, Berlin, 2007.

Certifications for protection layers in base liners, in the sense of the determination of their general suitability taking into account the requirements of the Landfill Ordinance (see DIN 19667, rounded aggregate or double-crushed stone with a grain size of 16 - 32 mm as a drainage layer) and a typical load of up to 900 kN/m², are only awarded for geosynthetic components in the combination protection layer (protection-layer system according to No. 1), and for complete systems according to No. 2. A protection-layer structure consisting of a minimum 10 cm thick sand layer and a BAM-certified separation geotextile is also permitted. In these cases, the protection efficiency does not need to be verified[2]. These protection-layer systems can of course also be used in capping seals.

As regards the determination of their general suitability, protection layers according to No. 3, i.e. the purely geosynthetic protective layers, are only approved for capping-layer sealing. They can be used in the base seal only in special cases, which are characterized by two conditions (see Section 8).

1. The particle-size distribution range of the drainage layer is more finely or more broadly graded than the size band 16 - 32 mm and/or the pressure exerted by the landfill is so low that the requirements of Section 6.2 are met when the protection-efficiency test according to Section 6.1 has to be performed in individual cases.
2. The temperatures pertaining at the base of the landfill are similar to conditions in natural soil. The mean temperature must be ≤ 20 °C.

For purely geosynthetic protection layers, the product characteristics which directly determine the mechanical protection can be adjusted to a certain extent to the conditions pertaining in each individual case in accordance with the protection-efficiency test to be carried out. For the nonwovens normally used, the mass per unit area can be varied to some

[2] This does not apply, when instead of sand other fine granular but sharp-edged materials (e.g. slag, ash, cullet) are used. Then, tests of the protection efficiency have to be performed with respect to scratches or other damage of the surface of the geomembrane, s. section 6.2. When indicated a geotextile has to be used to protect the surface.

extent. The Certification Document therefore gives a certain permissible range for these properties. However, for nonwovens in cap seals the mass per unit area must be at least 800 g/m², and for base seals at least 2000 g/m² (see Table 2). Such products with different mechanical properties, but which are made from the same resins and fibers with the same production process at the same factory, form a product family. The tests for durability and aging are usually performed on only one product from the family with representative mechanical-property values. For nonwovens, for example, this is a mass per unit area of 1200 g/m². The details are regulated in the Certification Document.

The object of approval, the requirements and test methods, the aforementioned special regulations as well as the requirements for quality management in production and installation of the protection layers are explained in detail below.

2. 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 Act (KrW / AbfG). The ordinance was most recently amended on the 02.05.2013 by Clause 7 of the Ordinance for the Implementation of the Industrial Emission Directive, for the Modification of the Ordinance about Environmental Inspections and for the enactment of the "Bekanntgabeverordnung", dated 17 October 2011 (BGBl. I No. 21 of 02. Mai 2013 p. 973). Annex 1, No. 2.1 of the DepV permits the use in sealing systems only of state-of-the-art geosynthetics (geomembranes, protection layers, plastic-drainage elements, plastic reinforcing grids, etc.), of polymers, and of serially produced seal-monitoring 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 seal-monitoring 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 protection layers for geomembranes in landfill sealings. The Guidelines are the technical basis on which BAM, at the request of the manufacturer, tests the suitability of protection layers 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 protection layers so that the final sealing system corresponds to the state of the art. These requirements are explicitly indicated in the certificate. The competent (federal) State authorities must ensure that these requirements form part of the approval 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 protection layer.

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 Annexes 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 such protection layers using the BAM Certification number is prohibited.

Changes in either the raw material or production process of the protection layers or dispositions for in-house quality control and third-party inspection of production require new Certification. If 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 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 (Federal Law Gazette I No. 22 of 29 April 29 2009 p. 900), most recently amended on the 02.05.2013 by Clause 7 of the Ordinance for the Implementation of the Industrial Emission Directive, for the modification of the Ordinance about Environmental Inspections and for the enactment of the "Bekanntgabeverordnung", dated 17 October 2011 (BGBl. I No. 21 of 02. Mai 2013 p. 973). First Regulation amending the Landfill Ordinance of 17.10.2011; Federal Law Gazette 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 Third Party 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 (Certification Guidelines Leak Detection 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.
- Guidelines for the Certification of Geomembranes in Landfill-Sealing Systems (Certification Guidelines GMB), BAM Federal Institute for Materials Research and Testing.
- Guidelines for the Certification of Geocomposite Drains in Landfill Cap-Sealing Systems (Certification Guidelines Geocomposite 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 Cap-Sealing Systems (Provisional Certification Guidelines Geogrids), BAM Federal Institute for Materials Research and Testing.

3. Objects Certified

3.1. General

The objects certified are geotextile protection layers in a protection-layer system with an additional granular protection layer (combined protection layer), complete systems of granular materials and essential geotextile packaging components, and purely geosynthetic protection layers. Geosynthetic components are essential if they serve not only as a temporary aid to installation, but also contribute to the long-term effectiveness of the protection layer. In the following, the geotextile protection layers in the combined protection layer, the essential geotextile components in the complete systems, and the purely geosynthetic protection layers are collectively termed geosynthetic components.

As a matter of principle, a protection-layer system certified on the basis of these Guidelines is also suit-

able for use in securing contaminated sites and for the sealing of landfills which are not subject to the Landfill Ordinance.

The object certified must be either factory-manufactured with defined, reproducible properties, or manufactured in accordance with an exactly stipulated process on the construction site.

Applicant and Certification holder is the producer of the object certified, i.e. usually the manufacturer of the geosynthetic components or the manufacturer of the complete system. For the Certification procedure, the manufacturer must have the support of the relevant raw-material suppliers and the manufacturers of the pre-products. In the case of complete systems, authorized installation contractors can be specified by the manufacturer in the Certification Document.

The geosynthetic components and the complete system must be described fully and clearly by the applicant. This includes a description of the production process and of the components and primary products used, 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, and the information on the characteristic properties of the product.

The object certified is exactly described in the Certification document, particularly in the case of complete systems, by a detailed explanation of its structure of geotextile components and granular protection layer and by the dimensions and the information given below.

The production must be internally and third-party monitored within the scope of a quality-management system.

The Certification Authority must be notified of and approve of any changes in the above. Should the manufacturer not notify such changes, the Certification becomes invalid.

3.2. Material and Properties of the Primary Products of the Geosynthetic Components

The Certification Document includes details on the resin manufacturer and on the resin (type designation) used in the primary products (e.g. fibers, filaments, tapes, fibrillated tapes, multifilament yarns etc.) from which the geosynthetic components are manufactured; in addition, it gives the manufacturer's specification for density, melt-flow index and, if relevant, for carbon-black content. Other confidential information on the resins (molecular mass distribution, additives etc.) and on the polymer-bound additives (manufacturer, type designation and exact formulation) or other additives, as well as sample material must be deposited with the Certification Authority. Additional details must be disclosed if these are necessary for the unambiguous definition of the material.

There must be a legally binding agreement between the manufacturer of the primary products and the manufacturer of the geosynthetic components 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 and primary products used. The clear definition of the materials, the feasibility of verification 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.

The type of primary products, their designation, where appropriate, information on the specification (mean value and permissible tolerances) of selected properties (e.g. fiber count and mechanical properties) and, where appropriate, the manufacturer, are specified in the Certification Document. Details of further essential properties must be confidentially deposited with the Certification Authority. The properties listed in the Certification document are checked in the in-house QC of the primary-product manufacturer, and in the goods-received control, the in-house QC and the external quality control of the manufacturer of the geosynthetic components (see Table 4).

The essential properties of fibers, filaments, foil tapes, fibrillated yarns, multifilament yarns, etc. are specified in Table 1. Other primary products may have different essential properties, which may be stipulated on a case-to-case basis based on this Table.

3.3. Properties of the Geosynthetic Components

The characteristics (hydraulic and mechanical properties) of the geosynthetic components are indicated in the Certification Document based on DIN EN 13257 (see Table 2). These properties are checked in the in-house and third-party production quality control.

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 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.

For the geosynthetic components (e.g. geocontainers) of complete systems, additional or other characteristic properties (such as the tensile strength of seams and connections; see DIN EN ISO 10321) may be required, and these can be specified in individual cases based on Table 2.

Insofar as products are used in complete systems which are not specifically manufactured for these, the geosynthetic products forming the essential components must possess CE marking in accordance with DIN EN 13257. The characteristic values can be taken from the CE declaration of performance document. Section 4 details the approval requirements for certain characteristic properties.

The data sheet of the geosynthetic components or of the complete system must document at least the data relevant for in-house quality control.

3.4. Properties of the granular protection layer

For complete systems, essential properties of the granular protection layer (type of material, particle size, calcium carbonate content, thickness and mass per unit area of protection layer) and the associated characteristic values are specified in the Certification Document. The characteristic values are used as the basis for the in-house and third-party inspection in the production of the complete systems.

3.5. Marking

The certified product must be marked and packaged with repeated identification marking according to DIN EN ISO 10320. The marking must detail at least the name of the product and the Certification number. The marking must be printed so that it is permanently legible. It must in particular be sufficiently durable to withstand transport, storage and the installation stress. Each delivery unit (for example, roll) must carry a label in accordance with DIN EN ISO 10320, which gives the manufacturer, the type of product or the product name, dimensions, weight, as well as an intra-company code (e.g. 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 Certification document as an Annex.

3.6. Manufacturing Plant and Manufacturing Process

The manufacturing plant and a detailed manufacturer's description of the manufacturing process are fixed and form part of the Certification Document. All special confidential details on the manufacturing process are deposited with the Certification Authority. Prior to issuing Certification, the Certification Authority will visit the manufacturing sites of both geosynthetics and primary products 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.

4. Requirements for the Geosynthetic Components

The following describes the Certification requirements for the properties of geosynthetic components. The tests are carried out by BAM in Division 4.3 and in test houses approved by BAM (see Section 13). Tests are carried out on the general physical and mechanical properties, on durability and aging, on protection effectiveness and soil retention.
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 Committee.

4.1. General Physical and Mechanical Properties

Table 2 lists the general physical and mechanical properties and associated characteristic values for nonwoven and woven fabrics. These are used as identifiers, as well as benchmarks in the scope of quality assurance.
For the nonwovens in protection-layer system No. 1, the characteristic value of the mass per unit area (defined as the mean value over the roll width – standard deviation) must be ≥ 1200 g/m². For nonwovens used as purely geosynthetic protection layers in capping layers, the characteristic value of mass per unit area must be ≥ 800 g/m². For nonwovens used for the exemption case (Section 8) in base seals as purely geosynthetic protective layers, the characteristic value of the mass per unit area must be ≥ 2000 g/m².
For other geosynthetic components, properties, test attributes, characteristic values and test methods are set based on Table 2. Adequate robustness is required to withstand the demands made by handling on site etc. (see Section 9). The nonwovens in protection layers according to No. 1 (combined protection layer) and the purely geosynthetic protection layers must belong to geotextile robustness class (GRK) 5. Geotextile packaging should be GRK 3. The technical process of packaging may require deviations from this. In these cases, special installation measures must be observed.

4.2. Durability and Aging

4.2.1. Resistance to Chemicals

The resistance to chemicals is tested in an immersion test based on DIN EN 14414 (see Table 3a No. 3.1). More information on the test procedures is given on the BAM Internet site[3]. The chemicals are selected from the list of concentrated media given there. The selection of the test media focuses on the function of the geosynthetic components in the protection layer and on the damage mechanisms (aging processes under exposure to chemicals) relevant to the particular material under landfill conditions.
For polyolefins (polyethylene (PE), polypropylene (PP)), testing is usually only carried out on the resistance to benzenes, aromatic hydrocarbons, paraffin, lubricating and fuel oils, diesel fuels, aliphatic hydrocarbons and oxidizing inorganic mineral acids. An aqueous solution containing 25 vol.-% concentrated nitric acid is used as the oxidizing inorganic acid.

4.2.2. Resistance to Oxidation and Hydrolysis

The resistance to oxidative degradation for geosynthetic components made of polyolefins is tested in forced air oven tests based on DIN EN ISO 13438, and in water immersion tests based on DIN EN 12447 each at 80 °C storage temperature (Table 3b No. 3.4 and 3.5)[4]. The storage period must be at least one year. The changes in mechanical characteristics (tensile strength and elongation at tensile strength) are investigated, as are the stabilizer content and crystallinity. The stabilizer 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 3.

[3] www.bam.de/de/service/amtl_mitteilungen/abfallrecht/index.htm.

[4] Müller, W. W., Jakob, I., Li, C. S. und Tatzky-Gerth, R.: *Durability of polyolefin geosynthetic drains*. Geosynthetics International, 16(2009), H. 1, pp. 28-42.

Requirements for other raw materials/product types (e.g. polyester) are set in analogy by transferring the requirements for resistance against oxidative degradation. For example, the immersion tests for the resistance to hydrolytic degradation in polyester geotextiles are described in Table 3 No. 3.6[5].

4.2.3. Resistance to Weathering

The test is performed according to the DIN EN 12224 test method (see Table 3 No. 3.2).
As a matter of principle, the geosynthetic components of the protection layers should be exposed as little as possible to UV-radiation, as this usually has a pronounced negative effect on plastics. UV-radiation degrades the stabilization and can initiate auto-catalytic reactions which then continue even after covering. Deviating from DIN EN 12224, the basic rule is therefore that all products, 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.

4.2.4. Resistance to Micro-Organisms

Soil-burial tests based on DIN EN 12225 in microbe-active soil are designed to ensure a minimum resistance to the diverse microbial attacks possible in a landfill (see Table 3 No. 3.3). This test is generally unnecessary for geotextiles made of polyolefins and polyester.

4.2.5. Environmental Compatibility of Additives and Processing Aids

Leachable or water-soluble additives and processing aids (e.g. finishes) must be environmentally safe. This must be demonstrated according to the procedure given in the FGSV leaflet[6] Section 6.28.

[5] 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). Faunhofer IRB Verlag, 1999.

[6] M Geok E - 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).M Geok E - Note on the application of geosynthetics in road-construction e-arthworks with checklists for the application of geosynthetics in the earthworks of road construction (C Geok E). FGSV-Verlag, Köln, 2005.

4.3. Soil Retention Capacity

Geotextile components used as erosion protection for granular protection layers (e.g. sand), must possess adequate soil-retention capacity. The retention capacity is quantified by the characteristic opening size according to DIN EN ISO 12956. The requirements are set in individual cases taking the filter rules into account[7].

5. Requirements for the Granular Protection Layer

With respect to chemical resistance – e.g. limitation of the calcium carbonate content, the constancy of volume, etc. – by analogy, the same requirements apply to the granular protection layers as do to the granular materials of the drainage layer. Here reference is made in particular to DIN 19667 and to GDA Recommendation E 3-12 "Suitability testing of granular drainage layers" in which the requirements for drainage-layer materials are extensively covered. The GDA recommendations are available on the website
www.gdaonline.de
The granular protection layer in protection system No. 1 (combined protection layer) must be sufficiently fine-grained to distribute the load over the nonwoven fabric. However, it must also fulfill the geometrical filter criteria opposite the filter layer with a particle size of 16 - 32 mm. The particle-size curve of the granular component in the combined protection layer must therefore lie within the area shown in Figure 1. However, if an approved filter geotextile is used, finer-grained granular material may also be used. Requirements on granular components in protection layers according to No. 2 (e.g. complete systems) are laid down for individual cases in the Certification Document.
Landfill-construction replacement materials can also be considered as long as the requirements on dura-

[7] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (Pub.): DVWK Merkblatt 221, Anwendung von Geotextilien im Wasserbau. Hamburg und Berlin: Verlag Paul Parey, 1992, 31 pages (out of print).

bility and particle size, and those of the DepV, are fulfilled.

The sand in protection-layer systems according to No. 2 (e.g. complete systems) must be chemically resistant according to the requirements of GDA Recommendation E 3-12.

In addition, the remarks in TL Gestein-StB[8] and DIN EN 13242 on quality assurance in construction with granular materials should be observed.

6. Verification of Mechanical Protection Efficiency

If common drainage layers are used (see DIN 19667), approved protection-layer systems according to No. 1 (combined protection layer) and No. 2 (e.g. complete systems) offer adequate protection to geomembranes in the base sealing up to loads of 900 kN/m². With the granting of Certification, tests on the protection efficiency for individual landfill construction projects are therefore no longer required. However, if special granular materials are used in the combined protection layer, and there are doubts about their strength, appropriate suitability tests must be performed. Only if loads are very high and the granular drainage layer very coarse may the protection offered by these systems need to be tested. In the special cases in which purely geosynthetic protection layers can be used in base seals (see Section 8), verification of protection efficiency must be performed on a case-by-case basis.

When using purely geosynthetic protection layers which have been approved for cap sealing, protection-efficiency testing should be performed both in the laboratory and in practical installation tests on a site test field in order to optimize the weight or other properties directly relevant to the mechanical protection function of the geotextile. For nonwovens, the mass per unit area may not be less than 800 g/m². Protection-layer systems approved for base sealing in accordance with No. 1 and No. 2 can be used without further proof in cap sealing.

6.1. Test Procedures for the Verification of Mechanical Protection

The mechanical protection is examined using a modified long-term plate-loading test. This protection-efficiency test is described in the GDA recommendation E 3-9 "Suitability testing of geosynthetics". A brief description is given in the following:

> An approx. 2 cm thick elastomer disk with a Shore A hardness of 45 – 50 is installed as the base layer in a cylinder with a diameter of 30 – 50 cm. A soft metal sheet with a thickness of 0.5 – 1 mm is placed on this, followed by test pieces of the geomembrane and the protection layer, and finally by a nonwoven separator and a load-distributing sand layer. The desired load is then applied by a pressure foot and regulated using a load cell device underneath the elastomer disk. The deformations of the geomembrane are visible as permanent, plastic deformations in the soft metal sheet. After the specified loading period the metal sheet is removed and the impressions are measured.

To transfer the loading conditions in the field to test conditions in the laboratory, a test load increased by a factor of 1.5 in relation to the maximum expected load on the sealing system is applied at a test temperature of 40 °C. Here, both the elevated temperature and the increase in load fulfill a time-lapse function in the deformation behavior of the geosynthetic components in the sealing system. The increase in load by a factor of 1.5 is designed to produce a deformation within 1,000 h which would otherwise require > 10^4 h under the design waste load

The deformation in the geomembrane preserved in the soft metal sheet (indentations or bulges) is calculated using the arc of the circle with the smallest extension of the indentation as the chord length, and the greatest depth of the indentation as the height. The arc elongation of this circle segment is then used as a quantitative measure of the size of indentation or bulge. The arc elongation thus determined

[8] Technische Lieferbedingungen für Gesteinskörnungen im Straßenbau (TL Gestein-StB), Ausgabe 2004 in der Fassung von 2007, Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln. (Technical delivery conditions for aggregates in road construction (TL Rock), Edition 2004 Version 2007, Research Society for Road and Transportation (FGSV), Cologne.)

can only serve as a measure of an impression which is still permissible, and of the associated area strain in the geomembrane liner, but not as a measure of the actual local strain in the geomembrane, which comprises area strain and outer-edge fiber strain according to the bending of the geomembrane along the indentation. At least three tests should be conducted to obtain a representative statement on the impressions brought about by the granular material of the drainage layer.

By increasing the load, the test time can be shortened and the test temperature reduced. The following load-increase factors for the test load must then be used:

Table a: Load-increase factors for different test conditions (time and temperature)

Test condition	Load-increase factor
1.000 h; 40 °C	1.5
1.000 h; 20 °C	2.25
100 h; 20 °C	2.5

For protection-layer systems in accordance with No. 2, in which protection is given by a sand layer, protection-efficiency testing can be performed in special cases with a load-increase factor of 1.5 and the test condition (100 h and 20 °C).

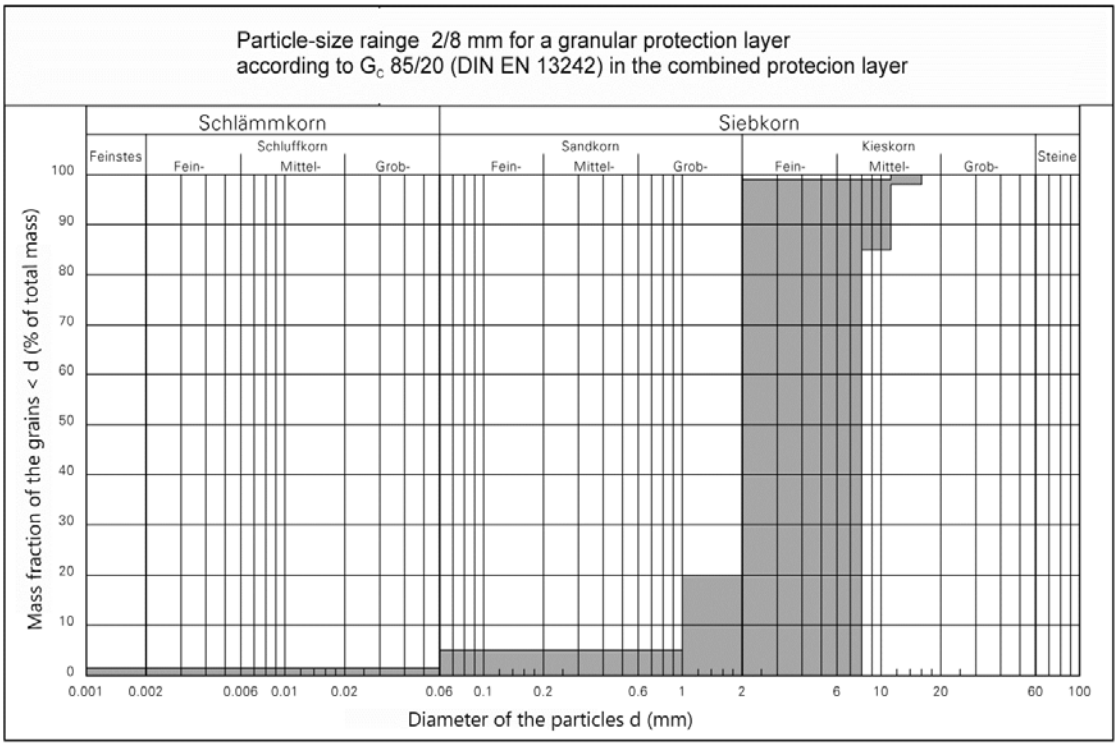

Figure 1: Preferred particle-size range for a granular protection layer fulfilling geometric filter criteria in the combined protection layer.

6.2. Requirements for the Mechanical Protection Effect

In nearly all protection-layer systems, deformations occur in the geomembrane which need to be quantitatively assessed by reference to the indentations in the soft metal sheet. This also applies to sand mattresses, where such impressions or bulges occur at typical places e.g. at the joints, at overlaps, or where impression marks result from structures of the packaging material.

Protection layers are suitable if the indentations conserved in the soft metal sheet after the mechanical protection-efficiency test with a particular applied load show arc elongations less than 0.25 %[9] and no

[9] The importance and derivation of this criterion are de-

damage (e.g. scratches, notches, grooves in the surface of the geomembrane) has occurred which might have an adverse effect on the functionality. The geotextile containment of the sand must not lose its retention capability e.g. because of damage. The verification of mechanical protection efficiency is confirmed up to loads equal to the test load reduced by the load-increase factor.

7. In-House[10] and Third-Party Production Quality Control

Regular factory and third-party inspection according to Annex 1 No. 2.1 of the DepV must ensure uniform quality of the production of primary products and of the geosynthetic components, and of systems made entirely in the factory (i.e. not first manufactured on site). These activities relating to the primary products, the geosynthetic components, and complete systems must be incorporated in a quality-management 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 geosynthetic components and complete systems must comply with the requirements of DIN EN 13257 Section 5.4 and Appendix 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.

Table 4 gives an example of the integration of incoming controls and tests, of in-house QC and of third-party inspection for geotextiles. The type and frequency of testing must be agreed with the certifying body and described in the Annex to the Certificate of Approval.

7.1. Goods-received Controls and Tests

Using the acceptance test certificate 3.1 based on DIN EN 10204, the relevant manufacturer of the primary products must check that the resins and additives – e.g. the base polymer and the additive batches – used in the primary products are the same as the materials used in the production of test samples for the Certification procedure. The results of these goods-received controls and tests as well as the in-house QC of the manufacturer of the primary product must be documented for each shipment of the primary product by an acceptance test certificate 3.1.

The type and frequency of the required incoming QC tests on the primary products as performed by the manufacturer of the geosynthetic components are set based on Tables 4 and 5 in the Annex to the Certification Document.

The conformity of the geosynthetic components and granular materials used with the materials used in the production of test samples for the Certification procedure must be checked by the respective manufacturer of the complete systems and documented for every delivery by inspection certificates 3.1 based on DIN EN 10204 from the respective manufacturer of geosynthetic components and granular materials. The type and frequency of the required incoming QC tests by the manufacturer of the complete systems are stipulated in the Annex to the Certification Document.

7.2. In-House Production Quality Control

As part of the in-house manufacturing QC of geosynthetic components and complete systems, specific characteristic properties of the products must be checked. These are, e.g. for nonwovens, the mass per unit area, the thickness, the tensile strength, the elongation at the tensile strength and the static-puncture behavior (CBR test) (see Table 4). The properties to be tested are specified in the Certification document. The values and permissible tolerances are also specified here. A declaration by the Certification Holder on the content, method and scope of incoming controls and tests and in-house manufacturing QC is, as an Annex, part of the Certification document.

The requirements on the scope of the tests are given in Table 5 for nonwovens. For other geosynthetic components or complete systems the test frequen-

scribed in Werner Müller, "HDPE Geomembrane in Geotechnics", Springer Publishers, Berlin, 2007, p 314.

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

cies are set within the scope of the Certification procedure according to the state of the art.
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 actually measured.

7.3. Third-Party Inspection

Manufacture of the geosynthetic components or the complete systems is subject to inspection by a neutral third-party institute agreed with BAM (see Section 13). This institute must have sufficient qualified personnel, the necessary test equipment, fulfill the requirements of the DIN EN ISO/IEC 17025 or the DIN EN ISO/IEC 17020 standards and be approved by the Certification body 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 material identification, verification and control of primary products and the testing of the properties of the geosynthetic components or complete systems, as well as audits of their fabrication and the 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 geosynthetic components and the complete systems, the tests listed in the Annex to the Certificate of Approval for identification and the properties of the geosynthetic component and complete systems must be performed. Table 4 shows an example for geotextiles. During the inspection visit, the laboratory and production must be visited and the records examined to monitor the in-house QC system and its extent.
- The third-party inspection must be carried out twice per year. Material sampling for the production test must be carried out by the third-party inspector. When monitoring a product family, one product of the family must be verified. 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 current inspection report, in which the third party inspection body presents its test results. The report is sent on a regular basis to the manufacturer being inspected.
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.

7.4. Shipping Documents

The requirements of in-house QC and third-party inspection also dictate the requirements on the nature and extent of the papers which must be included with a shipment of geosynthetic components or complete systems to document their quality. A delivery note is required which contains information on the manufacturer, the type designation, a list of roll numbers or numbers of the delivery units and the dimensions of the packaged geosynthetic components or of the delivery unit of the complete system. This includes an acceptance test certificate 3.1 based on DIN EN 10204 for the geosynthetic component with information on the batch numbers of the processed materials of the primary products and on the results of in-house QC and an appropriate certificate for the complete system (e.g. sand mattress) with information on the batch numbers of the processed materials, primary products and geosynthetic components, and the results of in-house quality con-

trol.
In addition, the third-party inspection certificate and the full Certification Document must be available on site. Its Annex contains the requirements for in-house and third-party inspection, and the transport, storage and installation instructions.

8. Exceptions for purely Geosynthetic Protection Layers in the Base Seals

Fine materials, typically with a particle size of 8 – 16 mm, are sometimes used as drainage layers, especially on slopes. In addition, if the design loads are low (e.g. less than 300 kN/m²), the following variation can offer sufficient protection:

a) In combinations of nonwovens and granular material with a particle size of 0 – 8 mm (see Figure 1), a nonwoven fabric with a weight per unit area less than 1200 g/m² can be used. A weight per unit area less than 800 g/m² is not however permissible. Apart from this, the rules for nonwovens and the granular protection layer according to No. 1 apply. In particular, the raw materials (resin, additives), the primary products, the manufacturing process and the place of fabrication of the nonwoven must be the same as those of the nonwoven already certified according to No. 1 protection layer systems, see section 1.

If in addition to the above requirement it is guaranteed that in the area of the protection layer temperature conditions are similar to those in natural soils (mean temperature ≤ 20 °C), then the following alternative can also be used.

b) Use of a purely geosynthetic protection layer directly under the granular drainage layer. The purely geosynthetic protection layer must be approved for cap sealing. The Certification document must expressly permit the use of this purely geosynthetic protection layer for this special alternative. A nonwoven fabric must have a mass per unit area with at least 2000 g/m^2.

The installation of these two alternatives a) and b) in base seals is permissible under the conditions specified when the mechanical protection efficiency has been verified with the test method detailed in Section 6.1 for the sealing structure chosen for the construction project. The requirements regarding mechanical protection efficiency stipulated in Section 6.2 must be met. Only a testing laboratory experienced in conducting the tests may be charged with performing these. The responsible authority must approve the selection of the testing laboratory.

9. Requirements for the Installation of the Protection Layers

As a matter of principle, certified protection layers for geomembranes may be installed only by specialist installation contractors who meet the requirements of the BAM Certification Guidelines for Installation Contractors. Proof of the required qualifications, equipment and experience can be demonstrated e.g. by the recognition as a specialist contractor by a quality-supervisory society of an industrial association demanding full compliance with the requirements of the BAM Certification Guidelines for Installation Contractors and inspection by an independent test institute recognized for its expertise and experience[11].
During transport, storage and installation, the requirements of the Certification document and the installation instructions of the manufacturer must be observed.

[11] The German trade associations of geomembrane manufacturers and installation companies, the Arbeitskreis Grundwasserschutz e.V. (AK GWS) (industrial association of geomembrane manufacturers and installers), and the Arbeitsgemeinschaft Abdichtungssysteme eV. (AGAS e.V.) (committee on waterproofing systems) have established a quality-supervision system of this type based on the BAM recommendations. The quality supervision is realized by auditing and inspection of installation contractors by BAM. The companies which have undertaken to be quality supervised by AK GWS e. V. or AGAS e. V. meet the requirements of this Guideline.

9.1. Verification of Stability

When installed, the geosynthetic components of the protection layer should not over their complete cross section be permanently subjected to tension from forces acting down the slope, from lateral spreading forces, etc., unless explicit details regarding this are given in the Certification document. A transfer of tensile forces into the geosynthetic components may not be taken into account in the verification of stability (i.e. using the geosynthetic component as reinforcement is not allowed).

Verification of stability of the sealing system must be carried out for each individual landfill project according to recognized engineering practice. This applies in particular to slip surfaces between the geomembrane and the protection layer and between the protection layer and the drainage layer, as well as to the "internal" shear strength of the granular protection layer component. To this end shear tests must be carried out under the particular conditions of the project to determine the friction parameters. Taking account of the safety factors, depending on the type of the parameter and the load case, guaranteed stability must then verified.

To verify the stability of the sealing structure both under construction, at any particular intermediate stages and in its final stage, refer to the GDA-recommendations E 2-7 "Stability of the sealing systems opposite sliding", E 2-21 "Verification of safety opposite lateral spread and deformation estimation for the landfill base" and E 3-8 "Frictional behavior of geosynthetics".

9.2. Measures against stressing caused by Installation and Construction

The installation of the drainage layer and the granular protection layer subject the geotextile components to particular stressing. Construction procedures must be chosen such that these protection-layer components are not damaged. In particular when placing the aggregate of the drainage layer, care must be taken to avoid any pulling, distorting or bowing of the geotextile components. Installation in a sliding manner by an angle-dozer is therefore excluded. The admissibility of "sliding" installation of the drainage layer for a complete system is regulated individually in the Certification document. "Sliding" installation of the granular drainage layer over a granular protection layer is permissible if the suitability of the procedure has been demonstrated on the test field. When nonwovens are used in accordance with the special rules in Section 8, it has proved expedient, especially in sloping areas, to increase the strength by inserting and needling a woven fabric onto the nonwoven. The woven fabric must be used only to increase the strength; it must have no significant impact on the protection efficiency. If necessary, the protection-efficiency test must therefore be performed on a sample without woven fabric. Only then need no further demands be placed on the long-term durability of the fabric. The wovens should be chosen so that a tensile strength (MD and CMD) of min. 1.5 kN/m at an extension of 3 % is achieved in a wide-width strip tensile test according to DIN EN ISO 10319 on the nonwoven/woven composite.

The protection layer may not be directly trafficked. Exceptions for special installation equipment for the protection layers are allowed only in accordance with the stipulations and details in the respective Certification document. Suitable roads for the construction vehicles must be constructed for the transport and placement of drainage aggregate.

9.3. On-site Quality Management and Third-party Inspection

The protection layers are part of the landfill sealing 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 manufacturer responsible for the quality of his work, the on-site third-party testing by an independent third party, and the monitoring by the competent technical authority ensure that the landfill-sealing system is constructed with the designed quality characteristics (see also the GDA recommendation E 5.5 "Quality Assurance for Geotextiles").

A quality-management plan in accordance with GDA recommendation E 5-1 "Quality-management Principles" must be drawn up. This must define the specific elements of quality management as well as the

responsibilities, material resources and activities in such a manner that the quality features derived from the design procedure and detailed in the Certification document and its Annexes are also complied with by the installed protection layer. The quality-management plan must provide for coordinated action between the installation contractor and all other parties on site, as this is essential in the multi-sequential construction process necessary for the installation and construction of the planned liner system.

The quality-management plan includes quality-assurance plans in which the verification tests on the individual components of the seal are described. The requirements listed here on the placement of the protection layers and the requirements of the manufacturer's installation instructions must be observed. Table 6 gives an overview of the nature and scope of the necessary quality-assurance measures in the case of geotextiles. 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 geosynthetic components placed must be included in the installation plan.

The installation contractor must have a foreman, experienced in installation and responsible for self-testing, present on site at all times during installation work.

On-site third-party inspection must be carried out by a qualified and experienced organization with adequate personnel and equipment. The requirements that must be fulfilled with regard to the qualifications and duties of the third-party inspector are described in the BAM Guidelines for on-site Third-Party Inspectors. The choice of the on-site 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 nature and extent of verification tests in connection with the third-party inspection are described in Table 7 for the case of geotextiles. Standard quality-assurance plans can be found on the BAM Internet page.

The on-site third-party testing body should be consulted at the planning stage to ensure that the design of geosynthetics is both professional and takes account of specific material characteristics, and that the state of the art is taken into account in the specification documents and the quality-assurance plan.

10. Changes, Notification of Defects and Period of Validity

Changes to the object certified, i.e. the materials, the primary products, the geosynthetic components, the dimensions, the production process, the installation procedure, the production plant, or the intended use, require a new Certification or a supplement thereto. Certification is usually granted without any restriction on limitation of validity. If the requirements, terms, and conditions of approval are violated in the production, transportation or installation, the protection layer thus manufactured and placed is not suitable for purpose and not certified. The third-party production inspector and/or the authorities responsible for approving installation must report to BAM any repeated or serious deficiencies discovered in the manufacture and installation of the protection layer, and any failures of landfill-liner systems associated with the object certified.

11. Tables of Requirements

Table 1: **Characteristic Properties[1] of the Primary Products (e.g. fibers, tapes, etc.)**

No.	Property	Requirement	Test method
1.1	Primary product type	Exact description, e.g. type of fibers, type of yarns, production process, finish, post-treatment etc.	-
1.2	Titer	Manufacturer's specification	DIN EN ISO 1973
1.3	Maximum tensile strength	Manufacturer's specification	DIN EN ISO 5079
1.4	Extension at Maximum tensile strength	Manufacturer's specification	DIN EN ISO 5079
1.5	OIT	Manufacturer's specification	ISO 11357-6
1.6	Density	Manufacturer's specification	DIN EN ISO 1183-1; Measurement on extrudate, annealed 1 h at 100° C in water bath
1.7	Melt flow rate	Manufacturer's specification	DIN EN ISO 1133
1.8	Enthalpy of fusion melting point:	Manufacturer's specification	ISO 11357-3
1.9	Carbon-black content	Manufacturer's specification	Thermogravimetric analysis based on DIN EN ISO 11358 or determined in accordance with ASTM D 4218 or ASTM D 1603.
1.10	Stabilizer content	Manufacturer's specification	Solid/liquid extraction; UV-Spectroscopy or HPLC Analysis on the extract. In-house procedure
1.11	Content of carboxyl end groups	Manufacturer's specification	Based on GRI GG7 and ASTM D 7409 or in-house procedure.
1.12	Content of polyethylene glycol	Manufacturer's specification	In-house procedure
1.13	Solution viscosity	Manufacturer's specification	GRI GG8

1) The selection of the test attributes depends on the material of the primary products. Supplemental information and tests may be necessary.

Table 2: **Characteristic properties of protection geotextiles**

No.	Property	Requirement[1]	Test method
2.1	Type of geotextile	Exact description, e.g. type of fibers, type of yarns, type of bonding, type of weave, picks per inch, post-treatment etc.	-
2.2	Mass per unit area	$(x^* - s) \geq 1200$ g/m² (For nonwoven fabrics in protection-layer systems in accordance with No. 1) $(x^* - s) \geq 800$ g/m² (For nonwoven fabrics in protection-layer systems in accordance with No. 3 in cap sealings) $(x^* - s) \geq 2000$ g/m² (For nonwoven fabrics in protection-layer systems in accordance with No. 3 in base sealings)	DIN EN ISO 9864
2.3	Thickness	Manufacturer's specification	DIN EN ISO 9863-1, Test pressure = 2 kPa
2.4	Maximum tensile strength	Manufacturer's specification	DIN EN ISO 10319
2.5	Extension at Maximum tensile strength	Manufacturer's specification	DIN EN ISO 10319
2.6	CBR force	Manufacturer's specification	DIN EN ISO 12236
2.7	Dynamic-puncture behavior	Manufacturer's specification	DIN EN ISO 13433
2.8	Characteristic opening size[2]	Manufacturer's specification	DIN EN ISO 12956
2.9	Protection-efficiency test (index test)[3]	Manufacturer's specification	DIN EN 13719

1) $(x^* - s)$:= mean value over roll width – standard deviation

2) Only required for the geotextile components of complete systems

3) Only required for geosynthetic components in the combined protection layer und for pure geosynthetic protection layers.

Table 3a: Requirements for the Durability of the Geotextiles

No.	Property	Test Attribute	Requirement	Test/Test Conditions
3.1	Resistance to chemicals[1] (concentrated liquid solutions)	Relative change in mass per unit area m	$\delta m \leq 25$ %	Immersion tests based on DIN EN 14414; Storage temperature 23° C; Storage of samples, from which at least 5 test pieces for the tensile tests can be punched out. Samples must be stored for at least 90 days and in any case until no further change in weight is measured. Tensile tests on the dried test pieces (see Table 2.4 and 2.5)
		Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max} in CMD	$\delta T_{max} \leq 25$ % $\delta \varepsilon_{max} \leq 25$ %	
3.2	Weathering resistance	Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max} in CMD	High resistance to weathering	DIN EN 12224
3.3	Resistance to Micro-Organisms	Relative change in mass per unit area m and	$\delta m \leq 10$ % $\delta n \leq 10$ %	DIN EN 12225, soil-burial testing in microbe-active soil; Storage of samples, from which at least 5 test pieces for the tensile tests can be punched out. Tensile test (see Table 2.4 and 2.5).
		Relative change in mean values of tensile strength T_{max} and elongation at max. tensile strength ε_{max} in CMD	$\delta T_{max} \leq 10$ % $\delta \varepsilon_{max} \leq 10$ %	

1) Additional information and explanations on the tests can be found on the Internet site www.bam.de/de/service/amtl_mitteilungen/abfallrecht/index.htm.

Table 3b: Requirements for Resistance to Aging Processes in the geotextiles[1]

No.	Property	Test Attribute	Requirement	Test/Test Conditions
3.4	Oxidative degradation in air	Change in external appearance	No pronounced changes	Air-oven aging based on DIN EN 13438; 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. Tensile test (see Table 2.4 and 2.5). 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} in CMD	$\delta T_{max} \leq 50$ % $\delta \varepsilon_{max} \leq 50$ %	
		Relative change in the mass fraction of antioxidants c_S	$\delta c_S \leq 85$ %	
3.5	Extraction	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 samples, from which at least 5 test pieces for the tensile tests can be punched out. Tensile test (see Table 2.4 and 2.5). 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} in CMD	$\delta T_{max} \leq 50$ % $\delta \varepsilon_{max} \leq 50$ %	
		Relative change in the mass fraction of antioxidants c_S	$\delta c_S \leq 90$ %	
3.6	Hydrolysis in water	Change in external appearance	No significant change	Hot-water storage based on DIN EN 12447; water temperature: 55, 65, 75 °C; storage time: at least one year; Storage of samples, from which at least 5 test pieces for the tensile tests can be punched out. Tensile test (see Table 2.4 and 2.5). 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 the crystallinity n and the 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} in CMD	$\delta T_{max} \leq 20$ % $\delta \varepsilon_{max} \leq 20$ %	
		Relative change of mean molecular weight N	$\delta N \leq 50$ %	

1) Additional information and explanations on the tests can be found on the BAM Internet site www.bam.de/de/service/amtl_mitteilungen/abfallrecht/index.htm.

Table 4: **Measures for Quality Assurance and Material Identification of Geotextiles**

No.	Property and Test Attribute	Acceptance test certificates for primary products	Inspection of incoming goods and in-house QC	Third-Party Inspection	Certification Testing
	Resin				
4.1	Melt flow rate (MFR)	■			■
4.2	Density	■			■
4.3	Molecular-weight distribution				**c.d.**
4.4	Additives				**c.d.**
4.5	Carboxyl end-group content or solution viscosity				**c. d.**
	Masterbatch				
4.6	Formulation				**c.d.**
	Finish				
4.7	Formulation				**c.d.**
	Primary products				
4.8	Melt flow rate		■	■	■
4.9	Density				■
4.10	Dimensions or titer	■	■		■
4.11	Strength and elongation	■	■		■
4.12	OIT or analytical determination of stabilizer content		■	■[1]	■
4.13	Carboxyl end-group content or solution viscosity			■[1]	■
	Geotextile				
4.14	Mass per unit area		■	■	■
4.15	Thickness		■	■	■
4.16	Maximum tensile strength/elongation		■	■	■
4.17	Static-puncture resistance (geosynthetic CBR test)		■	■	■
4.18	Check on needle breakage		■		
4.19	Cone-drop test		■		

c.d. = confidentially deposited with the Certification authority

1) Once per production year and for one product of a product family. The identification test method depends on the type of antioxidants used. The procedure is separately defined for the individual case

Table 5: **Extent of Tests on Geotextiles in the Scope of In-house QC**

No.	Characteristic	Test method	Test frequency[1]
5.1	Mass per unit area	see Table 2	every 300 m²
5.2	Thickness	see Table 2	every 300 m²
5.3	Strength and related elongation	see Table 2	every 3,000 m²
5.4	Static-puncture resistance	see Table 2	every 3,000 m²
5.5	Cone-drop test	see Table 2	every 20,000 m²

1) Proposed values; peculiarities in the production process and test frequencies, which are harmonized accordingly, are considered in individual cases.

Table 6: Type and Extent of Tests on Protection Geotextiles in the Scope of On-site Third-Party Inspection

No.	Test Attribute	Test	Frequency	Requirement and Tolerances
6.1	Thickness	DIN EN ISO 9863-1	at least every 5,000 m²	Requirement defined in Certification document
6.2	Mass per unit area	DIN EN ISO 9864	at least every 5,000 m²	Requirement defined in Certification document
6.3	Tensile strength and elongation at tensile strength	DIN EN 29073-3[1]; DIN EN ISO 10319	at least every 5,000 m²	Requirement defined in Certification document
6.4	Static-puncture force and displacement	DIN EN ISO 12236	at least every 5,000 m²	Requirement defined in Certification document

1) For the evaluation of the test results, the correlation between the test results according to DIN EN 29073-3 and those according to DIN EN ISO 10319 must be determined.

Table 7: Quality Assurance for the Installation of Protection Geotextiles

No.	Date and time of test	Parameters	Test method	Requirements	Sampling grid	Testing by	
						FPC	SI/TPI
7.1	Bid submission	Proof of suitability, Data sheets Certification Document	Checking on validity/ completeness and conformity	Certification Document Third-party inspection contract, date of last monitoring results	The products foreseen	-	SI (CD) TPI (A)
7.2	4 weeks before commencement of construction	Sliding-stability verification, shear parameters	Check for completeness and compliance with project specifications	Verification of sliding stability according to GDA E 2-7 during and after construction, shear parameters according to GDA E 3-8 project-related	All relevant sections	-	SI (CD) TPI (A)
		Installation plans, manufacturer's installation instructions	Specialist check on completeness	Taking into account major and subordinate gradients, subgrade	each plan	-	SI (CD) TPI (A)
7.3	Delivery	Delivery protocols Factory inspection reports	Check for completeness and compliance with project specifications; Identification	According to data sheet, contract specifications, Certification Document DIN EN 10204-3.1 B	every delivery	(A)	SI (CD) TPI (A)
		Appearance	Visual inspection	No transport damage, intact packaging, proper marking	every delivery	(A)	SI (A) TPI (RS)
		Transport and Storage	Visual inspection	Storage area meets requirements, professional transportation	every delivery		SI (A) TPI (RS)
7.4	Installation (including test field)	Identity in accordance with manufacturer's specification	Visual inspection	Conformity with delivery documents	every installation unit	-	SI (CD) TPI (CD)
		Placement by slope-direction or layout plan	Visual inspection, measuring	Installation instructions, installation plan	every geotextile, random samples	-	SI (A) TPI (RS)
		Overlap	Visual inspection, measuring	≥ 0.5 m without fixing ≥ 0.3 m with fixing (welding or gluing)	every overlap	-	SI (A) TPI (A)
		External appearance, geotextile	Visual inspection	Integrity	every geotextile	-	SI (A) TPI (A)
		External appearance, geomembrane	Visual inspection	Integrity	Exhumation, test field		SI (A) TPI (A)

No.	Date and	Parameters	Test method	Requirements	Sampling grid	Testing by	
7.5	Cover layer	Installation of drainage layer	Visual inspection, measuring	Installation immediately after sign-off, no displacements/distortions and folds in the geotextile; no direct trafficking, roads for construction vehicles ≥ 1 m, installation by "front dumping"	first layer placed	-	SI (A) TPI (A)

FPC = factory production control; SI = self inspection (site); TPI = on-site third-party inspection; A = active inspection; RS = random sampling; CD = check of documentation

12. List of standards

The currently valid version of the standard is applicable.

ASTM D 1603	2006	Standard Test Method for Carbon-Black Content in Olefin Plastics
ASTM D 7409	2007	Standard Test Method for Carboxyl End Group Content of Polyethylene Terephthalate (PET) Yarns
DIN 18200	2000-05	Assessment of conformity for construction products - Certification of construction products by Certification body – factory production control, third-party inspection and Certification of products
DIN 19667	2014-08	Drainage of landfills – design, construction and operation
DIN EN 10204	2005-01	Metallic products – Types of inspection documents
DIN EN 12224	2000-11	Geotextiles and geotextile-related products – Determination of the resistance to weathering
DIN EN 12225	2000-12	Geotextiles and geotextile-related products – Method for determining the microbiological resistance by a soil burial test
DIN EN 12226	2012-03	Geotextiles and geotextile-related products – General tests for evaluation following durability testing
DIN EN 12447	2002-03	Geotextiles and geotextile-related products – Screening test method for determining the resistance to hydrolysis in water
DIN EN 13242	2008-03	Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
DIN EN 13257	2010-06	Geotextiles and geotextile-related products – Characteristics required for use in solid waste disposals
DIN EN 13719	2014-10	Geosynthetics – Determination of the long term protection efficiency of geotextiles in contact with geosynthetic barriers
DIN EN 14414	2004-08	Geosynthetics – Screening test method for determining chemical resistance for landfill applications
DIN EN 14415	2004-08	Geosynthetic barriers - Test method for determining the resistance to leaching
DIN EN 29073-3	1992-08	Textiles; Test method for nonwovens; part 3: Determination of tensile strength and elongation
DIN EN ISO 1133-1	2012-03	Plastics – Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics
DIN EN ISO 1183 – 1	2013-04	Plastics - Methods for determining the density of non-cellular plastics – Part 1: Immersion method, liquid pyknometer method and titration method
DIN EN ISO 1973	1995-12	Textiles - fibers - determination of linear density – gravimetric method and vibroscope method
DIN EN ISO 5079	1996-02	Textiles - fibers – determination of breaking strength and elongation at break of individual fibers
DIN EN ISO 9001	2008-12	Quality management systems – Requirements
DIN EN ISO 9863-1	2014-08	Geosynthetics – Determination of thickness at specified pressures – Part 1: single layers
DIN EN ISO 9864	2005-05	Geosynthetics - Test method for the determination of mass per unit area of geotextiles and geotextile-related products
DIN EN ISO 10319	2013-08	Geosynthetics - Wide-width tensile test
DIN EN ISO 10320	1999-04	Geotextiles and geotextile-related products - Identification on site
DIN EN ISO 10321	2008-08	Geosynthetics - Tensile test for joints/seams by wide-width strip method
DIN EN ISO 11358-1	2014-10	Plastics – Thermogravimetry (TG) of polymers - General principles

DIN EN ISO 12236	2006-11	Geosynthetics – Static puncture test (CBR test)
DIN EN ISO 12956	2010-08	Geotextiles and geotextile-related products - Determination of the characteristic opening size
DIN EN ISO 13433	2006-10	Geosynthetics - Dynamic perforation test (cone drop test)
DIN EN ISO 13438	2005-02	Geotextiles and geotextile-related products - Screening test method for determining the resistance to oxidation
DIN EN ISO/IEC 17020	2012-07	Conformity assessment – Requirements for the operation of various types of bodies performing inspection
DIN EN ISO/IEC 17025	2003-06	General requirements for the competence of testing and calibration laboratories
DVWK-M 221	1992	Applications of geotextiles in hydraulic engineering
FGSV - M Geok E-StB	2005	Guidelines for the application of geosynthetics in road-construction earthworks
GDA E 2-7	2008	Sliding stability of the sealing systems
GDA E 2-9	2005	Use of geotextiles in landfill construction
GDA E 2-21	1997	Stability against lateral spreading and deformation estimation for landfill base
GDA E 3-8	2005	Friction behavior of geosynthetics
GDA E 3-9	2010	Suitability test for geosynthetics
GDA E 3-12	2011	Suitability test for granular drainage layers
GDA E 5-1	1997	Principles of quality management
GDA E 5-5	2010	Quality monitoring for geotextiles
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 Relative Viscosity Value
ISO 11357-3	2013-04	Plastics - Differential scanning calorimetry (DSC) - Part 3: Determination of temperature and enthalpy of melting and crystallization
ISO 11357-6	2013-04	Plastics - Differential scanning calorimetry (DSC) - Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)

13. Annexes to Certification Document, List of German State Codes, Testing and inspection bodies

Annex to Certification Document

Annex 1: Requirements and tolerances for in-house QC and third-party inspection,
Annex 2: Exact designation of the manufacturer with production sites and, if relevant, of installation contractors
Annex 3: Description of the production process
Annex 4: Manufacturer's raw-material declaration (resin type, additives, use of process recycled material, primary products)
Annex 5: Description of construction and arrangement of the marking
Annex 6: Description of the location of the markings
Annex 7: Description of the role 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 Federal Labor Gazette 4/91, page 61):

Baden-Wurttemberg	01	Lower Saxony	07
Bavaria	02	North Rhine-Westphalia	08
Berlin	03	Rhineland 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 inspection bodies for suitability testing and production monitoring

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