BAM

Bundesanstalt für
Materialforschung
und -prüfung

Guidelines for the Certification of Geomembranes used to line Landfills

Issued by

Division 4.3 "Contaminant Transfer and Environmental Technologies"

8th Edition, Mai 2017

These Certification Guidelines and the list of certified geomembranes, as well as additional Guidelines for geosynthetics and on-site 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 site:
http://www.tes.bam.de/en/mitteilungen/abfallrecht/index.htm.
http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm
Information on geomembrane manufacturers and approved installation contractors can be found under www.akgws.de (internet site of the professional association AK GWS e. V.) and under www.agasev.de (internet site of the professional association AGAS e. V.).
For the certification procedure the requirements of the actually valid German version of the Certification Guidelines are mandatory.

Introduction

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 DepV 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 DepV 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 DepV, 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 properties obtained from the tests and inspections in the country of manufacture guarantee that the materials, components and systems provide in the long-term a level of protection equivalent to that required by the DepV. 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 DepV came into force on October 16, 2009, the Advisory Committee was set up and established a working group which first revised the Certification Guidelines for Geomembranes – then over 10 years old – and then updated the revised version. The result of this work was the fourth edition of these Guidelines. In the meantime, new editions have been issued. The original certification concept, which included requirements to be met by the specialist installation contractors and the third-party testing authorities in addition to the requirements on the geomembranes, has proven itself effective. Therefore, no fundamental changes have been necessary. But the technical requirements have been updated to take account of knowledge and experience gained in the last years. The description of the test methods and the standards used here has been thoroughly revised and brought up to date.

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*; Dipl.-Ing. S. Baldauf, *GSE Lining Technology GmbH*; Dipl.-Ing. R. Drewes, *Landesamt für Umwelt Brandenburg;* H. Ehrenberg, *NAUE GmbH & Co. KG;* Dipl.-Ing. A. Elsing, *HUESKER Synthetic GmbH*; Dr.-Ing. B. Engelmann, *Umweltbundesamt*; Dipl.-Ing. F. Fabian, *LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg*; Dipl.-Ing. R. Heichele, *Bayerisches Landesamt für Umwelt (LfU);* 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)*; Dipl.-Ing. W. Spiel, *Landesdirektion Sachsen, Dienststelle Chemnitz*; 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. H. Zanzinger, *SKZ Süddeutsches Kunststoff-Zentrum*.

2. Other members of the Working Group:
Dr. J. Köhrich, *Hafemeister GeoPolymere GmbH*; M. Eng. Montserrat Garcia Estopà, *DOW Europe GmbH*; Dipl.-Ing. R. Kloth, *SABIC Europe*; Dipl.-Ing. V. Olischläger, *Naue GmbH & Co. KG*; M. Schweighuber, *AGRU Kunststofftechnik GmbH*; Dipl.-Ing. L. Veith, *Staatliche Materialprüfanstalt Darmstadt;* Dr. rer. nat. T. Weber, *Polyplast Müller GmbH* und Dipl.-Ing. R. Witte, *MPA Hannover.*

Table of contents

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 describes the requirements for the certification of geomembranes. The Guidelines are the technical basis on which BAM, at the request of the manufacturer, tests the suitability of geomembranes and, where appropriate, of jointing technology for the sealing of a landfill 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 geomembranes 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 additional provisions form part of the official 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 geomembrane sealing systems.

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 such geomembranes using the BAM certification number is prohibited.

Changes in either the raw material or production process of the plastic geomembrane or dispositions for in-house and third-party quality control (QC) of production require new certification. If installation and welding equipment used by the manufacturer or the installation contractor does not confirm its suitability and this can be demonstrated by new technical findings, i.e. if the factual situation, the state of the art or the legal situation have changed such that certification can no longer be issued, this too is grounds for revocation.

In the event of a 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; BGBl 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 objects certified are geomembranes used as convection barriers in base and cap liners of landfills governed by the DepV. For the on-site fabrication of the sealing component the geomembranes have to be welded according to the state of art. Only appropriate welding can inhibit the intrusion of water by capillary forces, hydrostatic pressure or via root penetration. Geomembranes certified on the basis of these Guidelines are also suitable for use in securing contaminated sites and for the surface sealing of landfills which are not subject to the Landfill Ordinance.

The geomembranes are described in the certification document by explicit particulars of the resin used in production (type, manufacturer, specification of density and melt-flow rate (MFR)), of the dimensions, the surface texturing and the production process. The geomembranes must carry identification markings and incorporate protective strips on their edges. The geomembranes must carry CE marking referring to DIN EN 13493. The geomembranes must fulfill the requirements given in these Guidelines and their production must be subject to in-house and third-party QC within the framework of a quality management system conforming to DIN EN ISO 9001.

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.

2.2. Resin

The manufacturer is obligated explicitly and in a legally binding manner to identify the resin used.

Both pre-compounded resins, in which all additives have already been mixed in by the manufacturer, and resins requiring addition of a masterbatch in geomembrane manufacturing may be used. Recommendations with respect to the masterbatch from the

manufacturer of the base polymer must be taken into account. The manufacturers of the resin and the masterbatch must contractually commit to notify the geomembrane manufacturer in due time of any change in the formulation of products supplied.
The batch shall incorporate a tracer additive defined in conjunction with the Certification Authority to ensure clear identification in the geomembrane.
When applying for certification of the geomembrane, the manufacturer must submit to the Certification Authority data sheets on the resins and additives employed containing at least the following information:

- Resin type, in the case of HDPE in accordance with DIN EN ISO 1872-1, and exact description and percentage by weight of the additives
- Molecular weight distribution and
- Specification of properties given in Table 5

This data will be confirmed by the Certification Authority in direct contact with the resin and masterbatch manufacturers. The descriptions and weight percentages of the additives, molecular-weight distributions and all other special data concerning resins and additives, i.e. the complete formulation, will be treated confidentially and filed accordingly by the Certification Authority. The content of recycled material from the production process (e.g. from edge trimming) may not exceed 5 wt %. It is laid down in the respective certification document. The use of regenerated resins is not permitted.

2.3. Dimensions

The maximum length per geomembrane roll and the width and thickness are given in the certification document. The requirements for nominal, minimum, mean and individual thickness values are given in Table 1. A basic requirement of the DepV is that the minimum thickness must be at least 2.50 mm, regardless of the surface texture of the geomembrane. The minimum permissible width is 5 m.

2.4. Surface Texture

Geomembranes may be smooth or textured on one or both sides. Texturing may be formed by embossing during production or by other processes which do not impair the material quality, or applied as particles subsequent to production. Special requirements for textured geomembranes are given in Section 4.4.

2.5. Identification Markings and Protective Strips

The geomembranes must carry clearly visible permanent identification markings approximately every 2 m². The identification markings must contain the following information which may be encoded if necessary:

XX/BAMOE/YY/ZZ/Manufacturers-Logo/Thickness/Width/Material/Surface/ProductionWeek/Year

OE is the organizational unit of BAM issuing the certification, XX is the (federal) State code (see Section 10), YY the Certificate Number and ZZ is the year of issue of the certification.
To protect against surface contamination, the surface of the geomembrane must incorporate a 15 cm-wide, colored differently and clearly visible protective strip in the smooth edge area where welding is to take place. The protective strip is applied during production. It must adhere sufficiently to prevent separation during transport and site handling but must not leave residues on the surface of the geomembrane when removed before welding is performed.

2.6. Manufacturing Plant and Process

The manufacturing plant and a detailed description of the manufacturing process are fixed and form part of the Certification Document. If so requested by the applicant, all particular details concerning the manufacturing process will be treated confidentially and filed by the Certification Authority.
Prior to issuing certification, the Certification Authority will visit the manufacturing site to verify the information provided on the manufacturing process and machines. The Certification Authority also checks that qualified personnel, machines, production areas, equipment/areas for resin storage and handling (base polymer and batch), testing machines and

other equipment are such as to ensure satisfactory continuous production and in-house QC in accordance with the requirements of Tables 5 and 6.
In individual cases, the manufacturer must demonstrate how potential risks of production defects resulting from the chosen manufacturing process (e.g. due to moisture in resin[1], thickness variations, damage to the surface of the membrane[2]) are prevented by appropriate measures in the production process and in quality management.

2.7. Jointing Technology

Welding is the only permissible method of joining the geomembranes in the production of the sealing components. The geomembranes must be placed with sufficient overlap and joined either by hot-wedge welding with a test channel (standard weld seams) or by hot-air extrusion-fillet welding. Other welding processes may be used only if their suitability has been documented and expressly approved by the Certification Authority. Grinding of the embossed structure of the geomembrane before hot-wedge machine welding may only be omitted and directly hot-wedge-welding be performed, if this is explicitly allowed in the Certification Document of the respective geomembranes.

3. Applicant and Certification Holder

The applicant and certification holder is the manufacturer of the geomembrane certified. The certified geomembrane must be sold by the manufacturer or a sales representative designated by him and named in the certification document. A geomembrane manufacturer who does not himself sell the geomembranes must designate at least one sales representative. Sales representatives are noted in the certification document after they have provided the certifying body with documentation of their capability and experience (e.g. training and experience of personnel, references) in the plastics and landfill sectors.

4. Testing Procedures and Requirements

The tests are carried out by BAM in Division 4.3, "Contaminant Transfer and Environmental Technologies", and in test institutes approved by BAM (see Section 10). Division 4.3 provides information on tests which are not yet described or not clearly described by test standards[3].
The minimum values given in the specification tables refer to the mean value minus the standard deviation unless otherwise specified.
The test procedures and requirements given in the requirement tables refer normally to geomembranes made from catalytic polymerized polyethylene (PE)[4]. They have a density (without carbon black) typically between 0.932 and 0.942 g/cm³, i.e. they are of medium density (MD), and MFR values (190 °C/5 kg) between 0.4 and 3 g/10 min. They typically contain a few percent of Hexen-1 or Octen-1 copolymers. Since their density with carbon black lies in the high density range (HD), such liners are generally referred to as HDPE liners.
For liners made from different resins, the tests are performed by appropriate modification of the instructions of the requirement tables. For geomembranes made from HDPE, BAM may waive the need for the following tests in certification:

- Tightness against hydrocarbons (Table 1 No. 1.10)

[1] Batches containing carbon black are particularly hygroscopic. Storage of such materials in dry rooms or in closed bags is therefore not usually sufficient to prevent moisture absorption. If the material is not processed immediately on delivery, pre-drying, for example using an industrial scale continuous-operation dry-air dryer is required or e.g. a degasification zone must be foreseen on the extruder.

Treatment by infrared-radiator is only allowed during the production run to insure a continuous and uniform cooling of the geomembrane. Subsequent treatment is not allowed.

[2] Such damage can occur in the subsequent application of structure particles.

[3] Additional details and explanations of the tests can be found on the Internet page of BAM: http://www.tes.bam.de/de/mitteilungen/abfallrecht/index.htm.

[4] Reference is made here to Werner Müller, "HDPE geomembranes in Geotechnics", Springer Verlag, Berlin, 2007.

- brittleness at low temperatures (Table 2 No. 2.6),
- Resistance to chemicals (Table 3 No. 3.1),
- Weathering resistance (Table 3 No. 3.5),
- microbiological resistance (Table 3 No. 3.6), and
- Resistance to root penetration and rhizomes (Table 3 No. 3.7)

Appendix 1 of the certification document lays down the properties of the geomembranes which are verified by in-house and third-party QC.
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 Requirements

Table 1, General Physical Requirements, lists the properties, tests and requirements for the individual test attributes which characterize the general nature of geomembranes. The following properties are determined: surface appearance, material homogeneity, carbon-black content and distribution, skew and waviness, thickness (individual values and mean), change in melt-flow rate due to processing, dimensional stability after warm storage, permeability to hydrocarbons and oxidative stability.

4.2. Mechanical Requirements

Table 2, Mechanical Requirements, lists the properties, tests and requirements for the individual test attributes which characterize the mechanical stress limits of the geomembranes. The following properties are determined: behavior under uniaxial and multiaxial deformation (tensile and burst test), tear-propagation resistance, resistance to multiaxial loading (CBR-puncture test), resistance to falling loads (perforation- or cone-drop test), low-temperature behavior (folding at low temperature, or cryogenic flex), relaxation behavior and weld-seam quality as determined in short-term testing on the construction site.

4.3. Requirements for Durability and Long-Term Behavior

Table 3, "Requirements for Physical Resistance and Long-Term Behavior of the Geomembranes", lists the properties, tests and requirements for the individual test attributes which characterize the resistance of geomembranes to chemicals, stress cracking, thermo-oxidative degradation, loss of stabilizers in water, weathering, microbe attack, and the damaging effects of plant roots and rhizomes.
These factors comprise the principal aging processes of polyolefinic materials. The tests are designed to furnish data on the basis of which the expected service life can be estimated using published scientific methods. In individual cases a modification of the test conditions and requirements may be necessary. For HDPE geomembranes, prediction of expected service life can be made on the basis of creep-rupture curves from long-term burst tests conducted on pipe specimens extruded or otherwise fabricated from the resin used to make the geomembranes[5]. However, as an alternative to creep-rupture pipe-burst testing, test procedures and requirements are being developed which allow evaluation of resins for which creep-rupture curves are not available. The test procedures under consideration here are stress cracking of notched specimens under constant tensile load, and oxidative stability under extraction in water. The performance requirements in these index tests are based on the performance of geomembrane resins which have proven their suitability in creep-rupture pipe-burst testing.
In addition, a new test procedure has been introduced for the characterization of the welding properties of a resin by a long-term peel test.

4.4. Requirements for Textured Geomembranes

Requirements for the resin used in the texturing and additional requirements for textured geomembranes depend on the type of texturing and the fabrication procedure employed.

[5] Reference is made here to Werner Müller, "HDPE geomembrane in Geotechnics", Springer Verlag, Berlin, 2007.

4.4.1. Texturing Resins

Texturing material or laminates applied subsequent to production should be made of the resin used to fabricate the base geomembrane or of another resin which has been used in certified geomembranes. If other resins are used, the combination of structural element and base geomembrane must have the same long-term behavior as the base geomembrane (see Table 3). The subsequent texture-application process must not have any negative impact on the geomembrane. Equally, auxiliary substances used in the process (e.g. blowing agents, gases etc.) must demonstrably have no detrimental effects on the materials.

4.4.2. Additional Requirements

The additional requirements for textured geomembranes are given in Table 4.

The bond between texturing particles and the base geomembrane must be not be superficial (in which case texturing can be removed by simple scratching with a fingernail); the bonding must result from fused interfaces. Auxiliary materials, e.g. adhesives, are not permitted.

As a matter of principle, the properties of textured geomembranes may not change detrimentally when compared to those of smooth geomembranes (see Tables 1, 2 and 3 of these Guidelines), with two exceptions (see Table 4): the dimensional stability of embossed textured geomembranes and the elongation at break. In particular, the yield strength and elongation at yield in uniaxial tensile testing and the bulge elongation in burst testing of specimens taken from the textured area must fulfill the requirements of Table 2. The texturing process must normally leave smooth (land) areas on the geomembrane for welding. The properties characterizing processing, i.e. nominal elongation at break, yield strength and elongation at yield of samples taken outside the textured areas (samples from the smooth edge area) must be the same as those of the smooth geomembrane.

The test procedures given in Table 3 are normally not required for textured geomembranes if a certified smooth geomembrane is made on the same production line from the resin already used to make textured certified smooth geomembrane. This does not apply to oxidation-resistance testing and to the resistance to extraction in hot water. The decision here must be on a case-to-case basis.

5. In-House[6] and Third-Party Quality Control

Inspection of incoming raw materials along with regular in-house production QC and third-party QC inspection in accordance with Annex 1 No. 2.1 of the DepV must be provided to ensure consistent quality in geomembrane manufacturing. These activities must be incorporated in a quality-management system certified in accordance with DIN EN ISO 9001. The valid certification document, the organigram detailing responsibilities, and the manufacturer's quality-management manual must be submitted to the certifying body.

The specifications for the base polymer and for the masterbatch are agreed on jointly by the geomembrane producer and the manufacturers of the base polymer and the masterbatch, respectively. The specifications for density, melt-flow rate and carbon-black content of the resin are entered as such in the certification document. This agreement forms the basis for acceptance-test certificates 3.1 on the basis of DIN EN 10204 for each delivery. For every delivery, the incoming QC of the resin deliveries must include random-sample testing and documentation by the geomembrane manufacturer of processing-relevant properties such as melt-flow rate, density of the base polymer, carbon-black and moisture content of the carbon-black batch. The test procedures required and their frequencies are given in Table 5.

The test attributes listed in Table 6 must be measured in in-house manufacturing QC using the procedures and frequencies given in the table. The test data generated in both in-house QC and in the third-party QC described below must fulfill the requirements and tolerances of the requirement tables and especially of Appendix 1 of the certification document. The test data must be archived for ten years so as to provide traceability of the test results for any

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

given geomembrane roll. This test data must be made available to BAM upon request. To ensure traceability, at a clearly visible location each geomembrane roll must carry a printed identification code as defined in the certification document and applied prior to shipment.
An acceptance test certificate 3.1 must be issued for each roll shipment on the basis of DIN EN 10204. The acceptance test certificate must clearly identify the specific rolls of those shipped on which the test values given were actually measured, and on which rolls the values are only derived from these tests according to the test frequency (see Table 6). Only those rolls for which test values can be stated in this manner may be identified and supplied as BAM-certified geomembranes.
Manufacturing of the geomembranes must be subject to QC inspection by a neutral third-party institute approved by BAM. This institute must have sufficient qualified personnel, the necessary test equipment, fulfill the requirements of the DIN EN ISO/IEC 17025 by accreditation as test laboratory, and of the DIN EN ISO/IEC 17020 by accreditation as inspection body. The inspection contract between the third-party inspector and the geomembrane manufacturer must be submitted prior to certification. The inspection comprises testing of the geomembranes, inspection of their manufacturing and their in-house QC. DIN 18200 applies to the inspection along with any additional requirements stipulated in the inspection contract between the third-party quality controller and the geomembrane manufacturer. The inspection contract must take account of the following requirements:

- When sampling the initial production of certified geomembranes, the third-party inspector must satisfy himself that the prerequisites for proper manufacturing and in-house QC are fulfilled.
- In third-party QC all tests given in Table 7 must be carried out on the pre-compounded resin (or base polymer), and on the geomembrane. During the inspection visit, the laboratory and production must be visited and the in-house QC records examined to monitor the QC system and its extent.
- The third-party QC must be carried out twice per year. If a manufacturer produces both certified smooth geomembranes and certified one- or two-sided textured geomembranes, third-party QC will be carried out twice per year on both the product group "smooth geomembranes" and the product group "textured geomembranes". Material sampling from the production must be carried out by the third-party inspector.

The inspection visits must normally be unannounced. Since BAM-approved geomembranes are often not continuously produced, the third-party inspector may take samples geomembranes which have already been produced. At least once per year, however, the third-party inspector should take samples from current production.
Proof of completed third-party QC is confirmed by inspection reports which the inspection institute will provide, together with a test-piece sample for identification purposes, regularly and of its own accord to the Certification Authority. This must be stipulated in the inspection contract. The inspection costs are borne by the Certification Holder. In the event deficiencies are discovered, the third-party QC institute will decide on the necessary measures to remedy these. Should repeated or serious deficiencies be discovered, the QC institute must inform the Certification Authority accordingly.

6. Installation

6.1. General

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.
Compliance with the requirements must be monitored by quality management measures. Quality management consists of self-inspection on the part of the installation contractor, of third-party inspection

by an independent institute charged with this task, and by the control by the responsible authority.

In order to ensure definition of state-of-the-art quality characteristics, the certification requirements must be taken into account in planning as well as in preparing the bidding specifications and the quality management plan. Therefore, it is necessary to call in the expertise of the third party inspector, even though it is not allowed that the third party inspector takes on responsibility for planning of the project.

The requirements apply in general to the installation of geomembranes. When used in base-lining systems of Class I landfills, geomembranes can be used as the sole liners; for Class II and III landfills, they can be used as convection barriers as one of the two liner components required. The second sealing component should then be a multilayer compacted clay or compacted mixed-grained mineral component (classic composite-liner system). In cap-sealing systems, geomembranes can also be used in landfills of class I as the sole sealing component. On cappings of landfills of classes II and III, in which two sealing components are required as a matter of principle, geomembranes can be used as a convection barrier in classic composite liners on compacted clay or compacted mixed-grained mineral components (classic composite-liner system), or on geosynthetic clay liners and on artificially improved mineral seals (e.g. Trisoplast) (modified composite-liners), or in combination with capillary barriers. If a sealing component is omitted with reference to Footnote 6 to Table 2 of Annex 1 of the DepV, the geomembrane as a convection barrier can be supplemented by a leak detection system.

When geomembranes are installed as part of a classical or modified composite liner system, the goal in design is to utilize the weight of the components above – e.g. protective and drainage layers, waste material and landscaped topsoil layers – to ensure full-surface contact between the geomembrane and the layer below the geomembrane. This smooth configuration and the resulting intimate contact prevent spreading between the two barrier layers of any leakage resulting from possible defects or damage. This ensures the preventive redundancy which is sought after in a composite-liner system. In other cases, e.g. when the geomembranes are installed over a subgrade layer or the capillary layer of a capillary barrier, the requirement for a smooth configuration of the geomembrane is derived from the need to prevent waviness, or folds arising from waviness, that would undergo excessive deformation due to the weight of the protective, drainage and topsoil layers. The limit for permissible local strain of HDPE geomembranes under multi-axial deformation at 40° C is 3 % in the long term, while the limit under multi-axial deformation at 20° C is 6 % in the long term.

6.2. Requirements for Installation Contractors

The geomembranes must be installed by a demonstrably experienced specialist firm using qualified personnel and equipped with the necessary machinery and other devices. The requirements are described in the BAM 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-control system of an industrial association demanding full compliance with the requirements of the BAM Guidelines for Installation Contractors and inspection by an independent inspection institute recognized for its expertise and experience[7].

6.3. Self Inspection and Third-Party Inspection

A quality-management plan in accordance with GDA recommendation E 5-1 "Quality-management Principles"[8] must be instituted. 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 of the in-

[7] Two competing German associations of geomembrane manufacturers and installation companies, namely the Arbeitskreis Grundwasserschutz e.V. (AK GWS) and the Arbeitsgemeinschaft Abdichtungssysteme eV. (AGAS.), have established a quality-supervision system of this type based on the BAM Guidelines for Installation Contractors. 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 or AGAS meet the requirements of this Guideline.

[8] The GDA recommendations are available on the website www.gdaonline.de.

stalled geomembranes listed in Annex 1 of the DepV and in these Guidelines are complied with. The procedures used must ensure satisfaction of the requirements described in these Guidelines for installation of the geomembranes and the provisions of the certification document and its Annexes. The quality management plan must provide for coordinated action between the installation contractor and all other parties on the site, as this is essential in this multi-sequential construction process, e.g. in the fabrication of the multilayer liner system. Self-testing by the installation contractor and third-party inspection in installation of the geomembranes must be included in the quality management plan. Quality control plans, in which the verification tests on the individual components of the sealing system are described, have to be part of the quality management plan.

Tables 8 and 9 list the nature and extent of the quality control measures and the control tests on the geomembranes within the scope of third-party inspection. A sample of standards for the quality control can be found on the BAM internet site[9]. Plans based on these standards have to be part of the quality management plan.

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

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 entitled "Third-Party Inspection in Installation of Plastic Components in Landfill Liner Systems".

6.4. Remarks on Planning and Design

The foundation soil must be firm enough to ensure that loading-induced deformations will not result in damage to the lining system. Deformation caused by settlement must not exceed the permissible elongation of the geomembrane.

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[10] 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".

Geometric progressions such as fillet radii and slope-head radii must be formed in accordance with DVS Guideline R 2225-4.

6.5. Subgrade for Geomembranes

Geomembranes may be installed only over suitable foundation layers (subgrade). The subgrade may also be designed to perform additional functions, e.g. those of a secondary sealing layer, capillary layer, levelling layer, base course or gas-collection layer. Here, special requirements arise regarding the surface of the mineral sealing in the classical composite liner, and these are described in the following section. For all other subgrades the requirements given in Section 6.5.2 apply.

6.5.1. The Surface of the Mineral Sealing Layer

For its function as the support for the geomembrane, the surface of the clay liner must be such that it will not cause short-term or long-term mechanical damage to the geomembranes in full-surface contact (intimate contact). Immediately before installation of the geomembranes, this surface must be subjected to acceptance inspection by the site-construction supervisor, the installation contractor and the third-party inspector for geosynthetics. The approval authorities may wish to participate in this acceptance inspection and should be advised accordingly.

The surface can only be accepted if it fulfills the following criteria:

- *In respect of materials:*
  The support surface must be of adequate bearing capacity, homogenous, fine-grained and closed. Particles > 10 mm ∅ as well as foreign bodies may not be present. Fine-gravel particles must be embedded in suspension, i.e. fully surrounded by

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

[10] The GDA recommendations are available on the website www.gdaonline.de.

cohesive sealing material. The surface must be free of particles > 2 mm ∅ and foreign material.

- *In respect of geometry:*
  As a matter of principle, the surface must be free of abrupt changes in height. Individual steps (impression-depth differences) are permissible up to a height of 5 mm. Deviations from level under a 4 m lath (straight edge) may not exceed 20 mm.

Analysis of field trials may lead to additional project-relevant evaluation criteria.

6.5.2. Surface Requirements for other Support Layers

The subgrade may be made of non-cohesive or weakly cohesive soil materials with a particle-size range of 0 – 32 mm or of recycled materials such as building rubble, crushed glass or slag in the same particle-size range. The particle shape, particle size and particle-size distribution of support-layer materials must be such as to exclude impermissible mechanical stressing of the geomembrane during both during construction and subsequent operation. This must be verified for the particular project by a protection-efficiency test (modified plate-bearing test) and by applying selected stressing modes in a field test plot for the construction procedure. The permissible mechanical elongation for geomembranes and the test procedures for the protection-efficiency test are described in the BAM Guidelines for Protection Layers[11].

The surface of the support layer must possess the inclinations and radii of curvature specified in the design. Deviations between planned and actual levels may not exceed ± 3 cm. Ledges, impression marks, and protrusions must be no larger than 2 cm. Certain subgrade materials (e.g. very rigid materials) may require case-by-case evaluation with regard to the need for stricter dimensional tolerances to avoid non-permissible stresses.

If a GCL is placed on the support layer first, it fulfills a mechanical-protection function for the geomembrane under the low surcharge loading of the cap-sealing system. This effect can be taken into account when selecting the support-layer materials in respect of particle shape, particle size and particle-size distribution.

In the modified composite liner, in which the mineral seal is replaced by another sealing component, the requirements for the supporting layer of this component from the suitability assessments of the LAGA ad-hoc Working Group "Landfill Technology" must also be observed[12].

6.6. Transport and Storage

The transport and storage instructions for geomembrane rolls are given in the appendix to the manufacturer's certification document. The quality-control measures defined for the site must ensure that these instructions are followed.

The transport of the geomembrane rolls must be always in accordance with the manufacturer's transport instructions. On the site itself, geomembrane rolls may only be transported by the installation contractor or personnel trained by the installation contractor using suitable transport equipment (e.g. lifting traverses).

An acceptance certificate 3.1 based on DIN EN 10204 with the results of the manufacturer's self-testing must be provided to the third-party inspector for each shipment along with the shipping documents (see also Section 5).

Storage of the geomembrane rolls must be such as to prevent indenting by stones, foreign bodies, planks etc. as well as non-permissible deformation of rolls resulting from stacking. A firm, flat and appropriately cleaned storage area must be prepared at the site prior to delivery of the geomembrane rolls.

6.7. Installation

Before installation of the geomembrane, the installation contractor and the third-party inspector must check that the geomembranes fulfill the require-

[11] Seeger, S. and W. W. Müller (2003). Theoretical approach to designing protection: selecting a geomembrane strain criterion. Geosynthetics: Protecting the Environment. N. Dixon, D. M. Smith, J. H. Greenwood and D. R. V. Jones. London, Thomas Telford**:** 137-152.
Seeger, S. and W. Müller (1996). "Requirement and Testing of Protective Layer Systems for Geomembranes." Geotextiles and Geomembranes 14(7-8): 365-376.

[12] www.gewerbeaufsicht.niedersachsen.de, sub-menus: Umweltschutz, Kreislauf- und Abfallwirtschaft, Deponietechnik, only German versions of the documents are available.

ments of its Certification Document and the project specifications and that the geomembrane rolls are not damaged in any way. A copy of the complete Certification Document must be available at the site.

Installation must be carried out according to an installation plan approved in advance by the third-party inspector and the responsible authority. When installation is complete, the plan is modified as necessary, providing the final plan of the installed liner system. Important principles to be followed in installation of geomembranes and in connecting geomembranes to HDPE structural components (e.g. constructions for pipe penetrations or foundations) are illustrated in the DVS 2225-4 Guidelines. Normally the installation procedure for the geomembrane must be included in the execution of the field test for the compacted clay liner or other second liner components in order to optimize installation opposite the other liner-system components.

Handling of the rolls during installation may be done only by the installation contractor or by personnel trained by the installation contractor using suitable transport equipment (e.g. lifting traverses) in accordance with the transport instructions of the geomembrane manufacturer. Special devices to control unrolling may be required on long or steep embankment slopes.

The geomembranes must be installed with minimal waviness to ensure a smooth intimate contact with the subgrade layer under subsequent loading. This requires adhering to a special procedure in the installation work[13], i.e. utilization of daily temperature cycling (the coefficient of linear thermal expansion of HDPE geomembranes $(1.5 – 2.5) \times 10^{-4}\ K^{-1}$ over a temperature range of 20° C to 70° C). A proven installation method known as “anchoring-bar technique” permits the perfectly smooth installation even for large areas and is described in the references given in the footnote below.

The load must generally be applied on the same or the following day, and at the latest on the second working day after the installation of the geomembrane. Experience has shown that waves up to several centimeters in height can be eliminated by waiting for ambient temperature to cool off later in the day. Waves in HDPE geomembranes cannot be smoothed out by simply loading from above. Even heavy loading is ineffective since HDPE is practically incompressible (Poisson ratio: 0.49). Weighing down long, high waves transforms them to small but very steep waves, causing high flexural strain in the geomembrane[14]. The timing and application sequence of ballasting by placement of the protective layer, the mineral drainage layer and other layers on a smooth geomembrane, which have to be heavy enough, are particularly important in this regard. This therefore must be done in the presence of the third-party inspector.

Basically, unrolled and placed layers of geomembrane have to be welded on the same or latest on the next day. A well-defined and proven installation method is the above describe installation procedure.

Care must be taken that the accumulation of condensate water under the geomembrane does not impair full-surface contact.

As a matter of principle, installation is not permitted during precipitation of any kind or over areas with standing water. Welding is not allowed at ambient temperatures below the dew point. Large-area installation of geomembranes is normally only possible from April to October. Installation outside this period is possible only under unseasonably favorable weather conditions. Installation outside of the period April to October may be done only with the consent of the responsible authority and the third-party inspector. Protection against inclement weather (e.g. a tent or heated tent) is normally required.

Each geomembrane when installed is given an identification number in the final diagram of the installation plan of the installed liner system. These identification numbers, the identification markings and the manufacturer’s roll numbers given in the shipping

[13] Averesch, U. B. und Schicketanz, R., *Installation Procedure and Welding of Geomembranes in the Construction of Composite Landfill Liner Systems – Focus on "Secured Modular Installation"*. In: Proceedings of the 6th International Conference on Geosynthetics, Atlanta, 1998, Editors Rowe, R. K., Industrial Fabrics Association International, Rosewill, USA, 1998.
Müller, W. W. (2007). HDPE Geomembranes in Geotechnics. Berlin, Germany, Springer Publishers.

[14] With regard to the size of elongations, see Soong T.-Y. and Koerner, R., *Behavior of waves in high-density polyethylene geomembranes: a laboratory study*. Geotextiles and Geomembranes 17(1999) pp 81 – 104.

documents must provide full traceability of all installed geomembranes with respect to production conditions and producer in-house QC.
Any damage to geomembranes which impairs sealing integrity or mechanical strength must be repaired. Repairs must be made following consultation with the third-party inspector. The type and location of all repairs must be documented in the final diagram and their welding process and test log sheets kept on record. The third-party inspector must check each repair and verify that it is fully satisfactory.

6.8. Welding and Site Testing

Welding and site testing of welds must be performed in accordance with the DVS R 2225-4 Guidelines. A welding trial using the welding machines and equipment, measurement and testing equipment intended for subsequent use must be conducted in the presence of the third-party inspector before welding work begins, or within the framework of the field trial. Subsequent use of procedures, machines or equipment other than those determined in the trial is allowed only with the prior consent of the third-party inspector.
Normally, only geomembranes made from the same resin may be installed and welded together. Should welding of geomembranes made from two different resins in exceptional cases be unavoidable, the following conditions apply: The resins within an MFR group in accordance with DIN EN ISO 1872 and within the range 0.3 to 1.7 g/10min in accordance with DVS Guidelines R 2207-1 are weldable with one another.
Table 9 shows the required site QC procedures within the framework of third-party inspection. In addition to site testing, laboratory testing of short-term mechanical properties must be carried out by the third-party inspector on at least 25 % of the welded samples made before seam welding or of the samples taken from either end of seams. At least two such samples have to be tested per installation day. The test procedures used must be in accordance with the DVS R 2226-3 Guidelines; the results must be evaluated in accordance with the DVS R 2226-1 Guidelines.
Only resins used in manufacturing of certified geomembranes are permissible for use as extrudates. In accordance with DVS Guidelines R 2211, a test certificate 2.2 for the extrudate according to DIN EN 10204 with designation of the of the raw material, the carbon-black batch and the results of the manufacturer's in-house QC on this shipment must be included with the shipment and be handed to the third-party inspector along with the shipping papers.

6.9. Protection Layers and Geocomposite Drains

A protection layer is required between the geomembrane and the granular drainage layer (e.g. 16 – 32 mm gravel). Its purpose is to protect the geomembrane from detrimental local elongation of any type during construction and subsequent operation of the landfill. The protection layer must be designed to withstand the anticipated maximum load and temperature expected in operation. In addition, materials and design must be such that the shear parameters required for static stability on slopes are not impaired by this loading.
Proof of suitability of protection layers for landfill-liner or capping systems must be furnished by means of a Certification Document in accordance with the BAM Certification Guidelines for Protection Layers.
In cap-sealing systems, a geocomposite drain can be installed which at the same time fulfills the function of a protection layer. Proof of suitability must be provided by a Certificate Document in accordance with the BAM Certification Guidelines for Geocomposite Drains.
After a section has been completed and the installed geomembranes have achieved flatness, the protection layer or the geocomposite drain must be installed on the day of membrane installation. Therefore, the geosynthetic protection layer and the geocomposite drain element must be installed by the installation contractor of the geomembrane. However, geotextile protection layers or geocomposite drains alone do not provide the necessary load to realize intimate contact according to the requirements above. The third-party inspector must verify that the installation of both, the protection layer and the geocomposite drain, as well as the granular drainage or recultivation layers, will cause no damage to the geomembrane below.

Further requirements regarding the installation of protection layers and geocomposite drains are given in Section 9 of the Certification Guidelines for Protection Layers, and in Section 5 of the Certification Guidelines for Geocomposite Drains.

7. Changes, Period of Validity and Notification of Deficiencies

Should any changes be made in the objects certified, i.e. the resin, geomembrane dimensions, surface texturing, identification markings, manufacturing method, place of manufacture, installation processes and welding technology used by installation contractors or the intended application field, a new or revised certification document is required.

Certifications are normally issued for an indefinite period. BAM reserves the express right of revocation as described in Section 1.

Should manufacturing violate the requirements of the certification document or should transport and/or installation procedures not conform to the instructions given on the state of the art, the certification document is no longer valid. It may not then be used as proof of suitability of the geomembranes in question. The third-party inspector and/or approval authorities must report to BAM any repeated or serious deficiencies discovered during quality control and acceptance procedure in manufacture and installation of geomembranes and any geomembrane-related failures.

8. Tables of Requirements

Table 1: **General Physical Requirements of Geomembranes**

No.	Property	Test Attribute	Requirement	Test/Test Conditions
1.1	Surface appearance	Visual appearance	smooth, closed surface (free of fissures, craters and pores); no damage	visual inspection in accordance with DIN EN 1850-2
1.2	Homogeneity	Appearance of cross section	free of pores, voids/cavities, foreign inclusions	DIN 16726:1986-12; Examine cut surfaces at 6x magnification.
1.3	Carbon-black content	Percentage by weight	2.0 to 2.6 wt.-%; Individual values may not differ by more than ±10 % from those specified in the certification document.	Thermogravimetric analysis based on DIN EN ISO 11358 or determined in accordance with ASTM D 4218 or ASTM D 1603.
1.4	Carbon-black distribution	Appearance of carbon-black agglomerates and dispersion (streaks or smears) in the microscope.	With respect to agglomerates: At least 7 Category 1 sections, the remaining sections not above Category 2.	10 microtome sections according to ASTM D 5596, classification of agglomrates in accordance with the relevant evaluation table and figures of ASTM D 5596 (agglomerates) and ISO 18553 (smears). No streaking or smears of poorly mixed areas. At least A1 and A2 of ISO 18553
1.5	Skew	maximum distance between edge of geomembrane and straight line over a length of 10 m when rolled out over a length of 12 m	All individual measurements must be ≤ 30 mm	DIN EN 1848-2
1.6	Waviness	Greatest clearance between geomembrane and level supporting surface over a length of 10 m when rolled out over a length of 12 m	All individual measurements must be ≤ 50 mm	
1.7	Thickness	Nominal thickness and mean	The arithmetic mean of thickness measurements must be ≥ nominal thickness	DIN EN ISO 9863-1, Method C, measurement between two pressure points. Thickness measurements made at a spacing of 0.2 m over the entire width of the geomembrane.
		Individual value	The minimum thickness is 2.50 mm; Thus for a nominal thickness of 2.50 mm all individual values must be ≥ 2.50 mm; For the individual values: Single value = mean value ± 0.15 mm; For nominal thicknesses ≥ 3.00 mm: Single value = mean value ± 0.20 mm;	

Table 1: **General Physical Requirements of Geomembranes (contd.)**

No.	Property	Test Attribute	Requirement	Test and Testing conditions
1.8	Melt-Flow Rate (MFR) and Density	MFR and density of resin; MFR and density of geomembrane;	$\lvert \delta MFR \rvert \leq 15$ %; $\lvert \delta MFR \rvert$: Amount of relative change between MFR of resin and geomembrane	DIN EN ISO 1133 DIN EN ISO 1183-1, Method A; Extrudate from MFR determination on the geomembrane and on the pellets (pre-compounded-resin pellets or base-polymer pellets)
1.9	Dimensional stability, change in dimension after storage at elevated temperature	Percentage change in dimension $\lvert \delta L \rvert$ of sides of square sample	$\lvert \delta L \rvert \leq 1.0$ % for all individual values. Difference over the width of the geomembrane < 0.4 % in case of smooth geomembranes and < 0.6 % in case of geomembranes with embossed structures.	BAM test procedure B14[1]. Samples taken 1.0 m apart over the width of the geomembrane; Storage at (120±2) °C for 1 hour; Measuring accuracy of the mechanical measuring gauge: at least 0.01 mm. Round off percentage value to nearest ‰.
1.10	Permeability[2]	Permeation rate of trichloroethylene at 23° C	≤ 80 g/m²d, determined from the line of best fit.	Steady-state determination at 23° C on specimens with 80 mm effective diameter and 2.5 mm thickness based on DIN EN ISO 6179:2010-08; BAM test procedure B4[1]
		Permeation rate of acetone at 23 °C	≤ 0.5 g/m²d, determined from the line of best fit.	
1.11	Oxidative stability[3]	Oxidative Induction Time (OIT)	≥ 40 min at 210° C	ISO 11357-6

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

2) Within the framework of the CE marking, which is a prerequisite for certification, the water-tightness according to DIN EN 14150 (permeation rate ≤ 10^6 $m^3 \times m^2 \times d^{-1}$) and the gas tightness according to ASTM D 1434 are also tested as harmonized tests. However, certified geomembranes must exclude any convective flow of water on account of their material structure (convection barrier).

3) The effectiveness of antioxidants depends on the temperature, among other things. An antioxidant which is still effective at application temperature may therefore not be measurable at the high temperatures of the OIT measurement. This is taken into account when assessing the oxidation stability in accordance with 1.11 and 3.3 and 3.4. Depending on the stabilization formulation presented to the certifying body, it may be necessary to use other analytical procedures to measure the change in the stabilization in the high-temperature and extraction tests.

Table 2: **Mechanical Requirements of Geomembranes**

No.	Property	Test Attribute	Requirement	Test/Test Conditions
2.1	Behavior under multiaxial deformation	Bulge elongation ε_w	$\varepsilon_w \geq 15$ %, without material yield	DIN 61551, D = 1000 mm, method with pressure control
2.2	Behavior in tensile test	Yield strength σ_y, Elongation at yield ε_y, nominal strain at breakε_{tb} in both MD and CMD	$\sigma_y \geq 15$ N/mm² $\varepsilon_y \geq 10$ % $\varepsilon_{tB} \geq 600$ % samples with smooth surface $\varepsilon_{tB} \geq 400$ % samples with imposed structured surface	DIN EN ISO 527-3, test specimen type 5, 23° C/50 % RH, crosshead speed: 100 mm/min; Method A for the evaluation of the nominal strain with reference value 50 mm; 5 specimens (taken in MD and CMD over the width of the geomembrane (smooth and structured)).
2.3	Resistance to Tear Propagation	Tear-propagation strength	≥ 300 N	ISO 34-1, method B (angle specimen according to Graves), Method B (nicked); The samples must be taken in MD and CMD.
2.4	Resistance to multi-axial loading	Static puncture resistance (geosynthetic CBR test)	≥ 6000 N	DIN EN ISO 12236
2.5	Resistance to falling loads (dynamic-puncture test)	Water tightness at point of impact	No loss of water tightness	DIN EN 12691, drop height 2000 mm, Method A (hard support)
2.6	Low-temperature brittleness (folding at low temperatures)	Visual appearance of flex edge	no cracks at -40° C	DIN EN 495-5, flex edge in MD and CMD
2.7	Relaxation behavior	Stress as a function of time at constant strain (stress-time-curve)	On the plot of stress vs. time, the stress after 1000 hours must be ≤ 50 % of the stress after 1 minute.	Stress relaxation test in accordance with DIN 53441:1984-01; 3 % constant strain, 23 °C, 50 % RH, specimens taken in MD and CMD
2.8	Seam quality	Deformation and failure behavior under shear stress	no shear failure of seam, pronounced necking in parent material next to seam	Peel test according to DVS 2226-2, crosshead speed: 50 mm/min
		Deformation and failure behavior under peel stress	no peeling of seam, pronounced necking in parent material next to seam	Peel test according to DVS R 2226-3, crosshead speed: 50 mm/min

Table 3: **Requirements on Durability and Long-Term Behavior of the Geomembranes**

No.	Property	Test Attribute	Requirement	Test/Test Conditions
3.1	Resistance to chemicals[1] (concentrated liquid solutions)[2]	Change in weight	Change in weight after re-drying 10 % ≤ 10 %	Immersion tests based on DIN EN 14414; Storage temperature 23° C; Immersion in sheet form of test pieces for tensile tests; Immersion must be over a period of 90 days or to attainment of steady-state weight, whichever occurs first; Tensile test on the dried test pieces (see Table 2.2)
		Change in nominal elongation at break ε_{tb} in CMD	Change in nominal elongation at break ≤ 10%	
		Yield stress σ_y and elongation at yield ε_y	$\sigma_y \leq 10$ % and $\varepsilon_y \leq 10$ %	
3.2	Resistance to stress cracking	Time to failure in creep-rupture test	According to ASTM D5397: full creep-rupture curve; According to DIN EN 14576: mean time to failure at a stress of 30% of the yield stress (23 °C/ 50 °RH) ≥ 400 h	DIN EN 14576 and ASTM D 5397; 10 % surfactant solution (Nonylphenol polyglycol ether, 9 – 10 links of the ethylene oxide chain, e.g., Igepal CO-630, Igepal BC-9, Tergitol NP-9, Arkopal N 100.); in the measurement of the creep-rupture curve the surfactant is not exchanged. Test on smooth geomembranes and on the smooth edge regions of structured geomembranes.

1) For HDPE geomembranes, testing of resistance to chemicals can generally be dispensed with.
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.

Table 3: Requirements on Durability and Long-Term Behavior of Geomembranes (contd.)

No.	Property	Test Attribute	Requirement	Test/Test Conditions
3.3	Resistance to thermal oxidative degradation in air	Change in external appearance	no change (see Table 1.1)	Air-oven aging based on ASTM D5721 and DIN EN 14575 in forced-air ovens (s. ISO 188, 4.1.4) storage temperature 80° C; Aging period 1 year
		Relative change in nominal elongation at break ε_{tb} in CMD.	Best-fit straight line through readings plotted against time; no significant decrease	Storage of test samples for the tensile tests in sheet form, tensile test (see Table 2.2)
		Yield stress σ_y and elongation at yield ε_y	Within the limits of measurement accuracy, σ_y and ε_y may not change, especially in the case of textured geomembranes.	
		OIT value after six months: OIT (0.5 y) Relative change of OIT value: ΔOIT = (OIT (0.5y) - OIT (1y)) / OIT (0.5y)	OIT (0.5 y) $\geq$ 25 min (mean value) ΔOIT = $\leq$ 0.3 with reference to the mean values	OIT measurement according to ISO 11357-6 at 210° C in aluminum crucible; The OIT value is determined in a sample weighing 4 – 6 mg taken from inside the geomembrane[1]
3.4	Resistance to extraction	Change in external appearance	no change (see Table 1.1)	Hot-water storage based on DIN EN 14415; water temperature 80° C; storage period 1 year
		relative change in nominal elongation at break ε_{tb} in CMD	Best-fit straight line through readings plotted against time, no significant decrease	Storage of test samples for the tensile tests in sheet form; tensile test (see Table 2.2)
		Yield stress σ_y and elongation at yield ε_y	σ_y and ε_y for textured geomembranes must not change in comparison to smooth liners.	
		OIT value after six months: OIT (0.5 y) Relative change of OIT value: ΔOIT = (OIT (0.5y) - OIT (1y)) / OIT (0.5y)	OIT (0.5 y) $\geq$ 30 min (mean value) ΔOIT = $\leq$ 0.6 with reference to the mean values	OIT measurement according to ISO 11357-6 in aluminum crucible; the OIT value is determined on a sample weighing 4 – 6 mg taken from inside the geomembrane[1]

1) The requirements apply to materials stabilized with phenolic and phosphitic antioxidants. If HAS are used the test methods and the requirements are still under evaluation.

Table 3: **Requirements on Durability and Long-Term Behavior of Geomembranes (contd.)**

3.5	Weathering resistance[2]	Change in nominal elongation at break ε_{tb} and in stress at failure σ_b each in MD and CMD	Section B10 of Notes on Tests[1]	See BAM Testing Procedure B10[1], DIN EN 12224
3.6	Resistance to micro-organisms[2]	visual assessment change in mass change in nominal elongation at break ε_{tb} and stress at failure σ_b each in MD and CMD Yield stress σ_y and Elongation at yield ε_y	no substantial change in mean values i.e., $\Delta m \leq 5$ %, $\Delta\varepsilon_b \leq 10$ % $\Delta\sigma_b \leq 10$ % σ_y and ε_y for textured geomembranes must not change in comparison to smooth liners.	DIN EN 12225, soil-burial testing in microbe-active soil; Storage of test samples for the tensile tests in sheet form, tensile test (see Table 2.2)

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.

2) For HDPE geomembranes, durability testing in accordance with 3.5 and 3.6 can generally be dispensed with.

Table 3: **Requirements on Durability and Long-Term Behavior of Geomembranes (contd.)**

No.	Property	Test Attribute	Requirement	Test and Test condition
3.7	Root- and rhizome-penetration resistance[4]	visual inspection	no penetration	FLL Method[2]; The tests are conducted on smooth geomembranes and seams.
3.8	Welding properties of resins[3]	Time to failure in long-term peel test	geometric mean $\geq$ 35 h	Long-term peel test according to DVS 2203-4 (Test Procedure) and DVS 2226-3 (Experimental Set-up), 80° C, 6 N/mm line load, 2 % surfactant solution (Arkopal N 150). Overlap seams with test channels produced by hot-wedge welding in the optimum welding-parameter selection (see BAM Testing procedure B11[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.

2) FLL: Research Society for Landscape and Construction, Bonn/Germany.

3) This time-to-failure requirement characterizes the welding properties of different resins. It is not suitable for evaluation of the quality of a welding seam per se. Welding seams not fabricated in the optimum welding-parameter field and which do not exhibit times to failure typical of that resin are substandard even if their times to failure exceed 35 h.

4) For HDPE geomembranes, durability testing in accordance with 3.8 can generally be dispensed with.

Table 4: **Additional Requirements for Textured Geomembranes**

No.	Property	Test Attribute	Requirement	Test and Test condition
4.1	Thickness in textured areas	Thickness	The thinnest point in the textured geomembrane must not be below the specified minimum (2.50 mm, or for thicker geomembranes, the appropriate nominal thickness)	DIN EN ISO 9863-1, Method C
4.2	Dimensional change after storage at elevated temperature	Value of relative change $\lvert \delta L \rvert$ of sides of square sample	$\lvert \delta L \rvert \leq 1.50$ % for all individual values for embossed texturing and $\lvert \delta L \rvert \leq 1.00$ % for all individual values for applied texturing, respectively. Difference over the width of the geomembrane < 0.6 % and < 0.4 %, respectively	Table 1 No. 1.9
4.3	Texturing homogeneity of applied texturing	Nominal amount and variation of texturing area weight	Requirement set for each case individually	Determination on a specific specimen area (typically 100 cm²)
		Uniformity of the spray pattern	Comparison with reference samples provided to Certification Authority	visual inspection
4.4	Particle adhesion for applied texturing	Behavior in shear-box test, variation in friction parameters	No peel-off or removal of texturing, no significant additional variation in the friction parameters	DIN EN ISO 12957-1, Contact surface geomembrane and nonwoven fabric (1200 g/m²); Vertical loads: 100 to 300 kPa
		Long-term shear test	Assessment of times to failure: 10,000 h at 80° C; Test pressure: 50 kPa; Inclination: 1:2.5	Long-term shear tests based on DIN EN ISO 25619-1; See BAM Testing Procedure B15[1]
		Scrape strength	Requirement set for each case individually	Method of the State Institute for Materials Testing and Production Technology (MPA) Darmstadt; See BAM Testing Procedure B13[1]
4.5	Chemical resistance of bonding of texturing particles	Change in scrape strength	Change in mean value ≤ 10 %	Immersion in substances 5 and 9 (see Table 3 No. 3.1.); Method see Section B12 Notes on Tests[1]
4.6	Stress-crack resistance (creep-rupture test)	Time to failure	geometric mean of times to failure ≥700 h	Creep-rupture test based on DVS 2226-4; time to failure determined on 5 test specimens at 80° C und 4 N/mm² tensile stress in a 2 % surfactant solution (Arkopal N150) Section B8 of Notes on 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 5: **Type and Extent of Tests on Resin and Carbon-Black Batch in scope of In-House Quality Control of Geomembranes by Manufacturer**

No.	Test Attribute	Test/Test Specimens	Frequency	Requirement and Tolerances
5.1	Density	DIN EN ISO 1183-1, Procedure A, extrudate from MFR determination on pellets (resin or base-polymer pellets)	Random samples from every shipment	Requirement defined in certification report
5.2	Melt flow rate (MFR)	DIN EN ISO 1133 Resin pellets or base-polymer pellets	Random samples from every shipment	Requirement defined in certification report
5.3	Weight percent carbon black	Thermogravimetric analysis based on DIN EN ISO 11358 or determination by ASTM 1603. Carbon-black pellets	Random samples from every shipment	Requirement defined in certification report
5.4	Weight percent of volatiles, moisture	Weight loss in oven according to DIN EN 12099, resin pellets or base-polymer pellets and carbon-black batch pellets	Random samples from every shipment and before every production start-up, or at least once per production week	< 0.10 wt % in precompounded resin or base polymer
				< 0.25 wt % Carbon-black batch
5.5	Bulk density[1]	DIN EN ISO 60, base-polymer pellets and carbon-black batch pellets	Random samples from every shipment and before every production start-up, or at least once per production week	Metering procedure and process set in quality-management manual

1) Only for volumetric metering of carbon-black batch.

Table 6: **Type and Extent of Tests on Geomembranes in scope of In-House Quality Control by Manufacturer**

No.	Test Attribute	Test/ Sample material	Frequency	Requirement and Tolerances
6.1	Thickness	DIN EN ISO 9863-1, Method C	Continuous automatic monitoring[1] with mechanical control measurement every 300 m	Requirement defined in certification report; Roll certificate must show at least the minimum and maximum values of control measurement.
6.2	Visual appearance	Table 1 No. 1.1	Continuous	Table 1 No. 1.1; Roll certificate must confirm satisfactory appearance.
6.3	Skew and waviness	Table 1 No. 1.5 and 1.6	Each production start-up[2]	Table 1 No. 1.5 and 1.6 Perfect straightness and flatness are confirmed in acceptance test certificate.
6.4	Weight percent carbon black[5]	Table 1 No. 1.3	Each production start-up and change in carbon-black batch lot[3] and at least every 900 m	Requirement defined in certification report Acceptance test certificate must give test procedure and individual values obtained
6.5	Homogeneity of carbon black distribution[5]	Table 1 No. 1.4	Complete measurement (10 microtome sections) each production start-up and change in carbon-black batch lot and partial measurement[3] with at least one microtome section every 900 m	Table 1 No. 1.4; If the partial-measurement result is Category 2, a complete measurement must be carried out; in the acceptance test certificate, the result is given as Category 1 or Category 1/ Category 2.
6.6	Yield stress Elongation at yield, Nominal strain at break	Table 2 No. 2.2; Crosshead speed: 100 mm/min up to 20 % elongation, thereafter 200 mm/min; Three specimens, MD and CMD, from the edge areas and the middle of the geomembrane[4]	Each production start-up and at least every 300 m	Requirement defined in certification report Roll certificate must show the minimum and maximum values determined in MD and CMD.
6.7	Stress-cracking resistance	Table 3 No. 3.2	Ruling in accordance with DIN EN 13493	Table 3 No. 3.2

1) If there is no continuous automatic thickness measurement, thickness must be measured ultrasonically every 10 lin. m over the width of the geomembrane.
2) Production startup means: Re-start after machine stoppage or change of resin or thickness.
3) A higher test frequency may be specified in individual cases after a production start-up or change of batch lot.
4) The taking of specimens from the structured area and their assessment are regulated in the respective certification document.
5) Only required when carbon black (batch) is added by the geomembrane manufacturer.

Table 6: **Type and Extent of Tests on Geomembranes in scope of In-House Quality Control by Manufacturer (contd.)**

6.8	Plunger-puncture (CBR) force	Table 2 No. 2.4	Smooth geomembranes: Ruling in accordance with DIN EN 13493 Textured geomembranes: once per production day	Table 2 No. 2.4; Roll certificate must give minimum and maximum values.
6.9	Melt-flow rate and change in melt-flow rate	Table 1 No. 1.8; samples from the geomembrane and the texturing material	Each production start-up and at least every 900 m	Requirement given in certification document; In the acceptance test certificate, the result is given according to Table 5 No. 5.2 and the difference to the result for the resin.
6.10	Dimensional stability	Table 1 No. 1.9; specimens taken from the edges, the middle of the geomembrane and from other critical locations (e.g. transition between smooth and textured areas)	Each production start-up and at least every 300 m	Table 1 No. 1.9; Roll certificate states individual values and sample locations.
6.11	Area weight of texturing for applied texturing	In-house procedure	Each production start-up and at least every 300 m	Requirement defined in certification report; Roll certificate must give minimum and maximum values.
6.12	Texturing adhesion for applied texturing	In-house procedure	Each production start-up and at least every 300 m	Requirement defined in certification report; Roll certificate must confirm satisfactory adhesion.

Table 7: Type and Frequency of Testing for Third-Party Inspection of Resin, Carbon-Black Batch and Geomembranes

No.	Test Attribute	Test	Sample material	Requirements and Tolerances[1]
7.1	Density	Table 5 No. 5.1 Table 1 No. 1.8	Resin / Geomembrane	Requirement defined in certification report
7.2	Melt flow rate (MFR)	Table 5 No. 5.2 Table 1 No. 1.8	Resin / Geomembrane	Requirement defined in certification report
7.3	Change in MFR	Table 1 No. 1.8	Resin / Geomembrane	Requirement defined in certification report
7.4	Thickness	Table 1 No. 1.7	Geomembrane	Requirement defined in certification report
7.5	Visual appearance of surface and cross-section	Table 1 No. 1.1 and 1.2	Geomembrane	Table 1 No. 1.1 and 1.2
7.6	Visual appearance of identification markings	visual inspection	Geomembrane	Section 2.5 and requirement according to certification document
7.7	Weight percent carbon black	Table 1 No. 1.3	Geomembrane	Requirement defined in certification document
7.8	Homogeneity of carbon-black distribution	Table 1 No. 1.4	Geomembrane	Table 1 No. 1.4
7.9	Dimensional stability	Table 1 No. 1.9	Geomembrane	Table 1 No. 1.9 and Table 4 No. 4.2
7.10	Yield stress, Elongation at yield, Nominal strain at break	Table 2 No. 2.2	Geomembrane	Requirement defined in certification document
7.11	Static puncture resistance (geosynthetic CBR test)	Table 2, 2.4	Geomembrane	Table 2, 2.4
7.12	area weight of texturing (applied texturing only)	Table 6, 6.11	Geomembrane	Table 6, 6.11
7.13	Texturing adhesion for applied texturing	Table 4 No. 4.5 and Table 6 No. 6.12	Geomembrane	Table 4 No. 4.4 and Table 6 No. 6.12
7.14	Oxidative induction time (OIT)	ISO 11357-6 at 210° C	Geomembrane	Table 1 No. 1.10
7.15	Type and content of Tracer	stipulated on case-by-case basis, test carried out by Certification Authority	Geomembrane	confidential, disclosed to Certification Authority

1) As a matter of principle, the requirements of the requirement tables must be met. In addition, Annex 1 of the certification document lays down requirements and tolerances which characterize the particular properties of the respective approved geomembrane.

Table 8: Quality control for Geomembrane Installation

No	Date and time of test	Parameters	Test method	Requirements	Sampling grid	In-house QC test	Self-inspection, installer (SI) /third-party inspector (MI/TPI)
8.1	Bid submission	Declaration of conformity, certification document	Check for validity and completeness	Third-party inspection contract, date of last monitoring results	the planned products	_	SI (D) TPI (A)
8.2	4 weeks prior to start of construction	Protection efficiency	Check for completeness and compliance with project specifications	See Certification Guidelines for Protection Layers: no inadmissible stresses in the geomembrane during installation and subsequent operation, surface strain in dented areas max. 0.25 %, test based on GDA E 3-9	all relevant layers	_	TPI (A)
		Verification of sliding stability shear parameters	Check for completeness and compliance with project specifications	Verification of sliding stability according to GDA E 2-7, shear parameters according to GDA E 3-8, project-related	all relevant layers	_	SI (D) TPI (A)
		Installation plans, manufacturer's installation instructions	specialist review as regards completeness	DVS 2225-4, certification report	each plan	_	SI (D) TPI (A)
8.3	Delivery	Delivery notes, manufacturer's test certificates, CE Accompanying Document	Check for completeness and compliance with project specifications, identification	according to data sheet, bill of quantities, certification report, EN 10204-3.1	every delivery	(A)	SI (D) TPI (A)
		Appearance	Visual inspection	no transport damage, proper identification	every delivery	(A)	SI (A) TPI (RST)
		Transport and Storage	Visual inspection	Storage area meets requirements, professional transportation	every delivery	_	SI (A) TPI (RST)
8.4	Installation, Preparation	Surface of the Mineral Sealing Layer	Inspection, measuring	Firm support area, closed surface free of particles > 2 mm ∅ and foreign bodies, particles < 10 mm ∅ embedded in suspension, steps up to 0.5 cm permissible, surface evenness ≤ 2 cm under 4 m straight edge	every surface to be released	_	TPI (A)
		Surface of other support layers	Inspection, measuring	Particles from 0 to 32 mm, project-related protection-efficiency test, steps ≤ 2 cm	every surface to be released	_	TPI (A)

FPC = factory production control, SI = self inspection (site), TPI = third-party inspection, RST = random-sample testing, A = active check, D = check of documentation

Table 8: Quality control for Geomembrane Installation (contd.)

No.	Date and time of test	Parameters	Test method	Requirements	Sampling grid	FPC test	by SI/TPI
8.5	Installation, Laying and welding	Proof of qualification of welding personnel	Visual inspection	DVS 2212-3, proof: Staff of installation contractor	each welder	_	SI (D) TPI (D)
		Thickness (minimum thickness)	measuring	see Certification Guidelines Geomembranes	each roll	_	SI (A) TPI (RST)
		External appearance GMB	Visual inspection	BAM Guidelines, no bubbles, inclusions etc.	every roll	_	SI (A) TPI (RST)
		Installation of GMB according to installation plan	Visual inspection	Unrolling with suitable equipment, DVS Guideline 2225-4	every length	_	SI (A) TPI (A)
		Method examination	Device setting	Device-specific	each unit	_	SI (A) TPI (RST)
		Trial welding	Inspection, measuring	Adjust welding parameters to the current site conditions.	every working day	_	SI (A) TPI (RST)
		Welded-joint inspection, construction site	Field test	DVS 2225-4, Visual inspection of tensile peel test	every test weld, beginning and end of each double seam	_	SI and TPI (A)
			Ultrasonic testing	DVS 2225-4	Every double seam, approximately every 10 m	_	TPI (A)
		Welded-seam inspection, laboratory	Laboratory test	DVS 2226 Parts 2 and 3, both parts of seam,	at least 25 % of the seam samples of the SI (at least 2 per working day)	_	TPI (A)
		Repair work	Visual inspection	DVS 2225-4	every flaw	_	SI (A) TPI (A)
		Welding and inspection reports	Check for completeness	DVS 2225-4	every report	_	SI (A) TPI (D)
		Leak test with compressed air and log (double seams), with vacuum (extrusion-fillet welds)	measuring	in accordance with BAM certification, DVS 2225-4	every seam	_	SI (A) TPI (RST)
8.6	Placement of subsequent layers	Waviness and cleanliness of the GMB surface (no foreign bodies)	Visual inspection	As soon as possible after release, no later than 2 days after installation to temperature-induced deformations, placement on smooth GMB	every released section	_	SI (A) TPI (A)

FPC = factory production control, SI = self inspection (site), TPI = third-party inspection, RST = random-sample testing, A = active check, D = check of documentation

Table 9: Type and Extent of Tests on Geomembranes in the Scope of Third-Party Inspection

No.	Test Attribute	Test and Sample material	Frequency	Requirement and Tolerances
9.1	Thickness	Based on DIN EN ISO 9863-1, Method C, measurement between two pressure points. Site testing can be based on this method and use measuring probes (scale division 0.1 mm). This means that certain variations in the radius of the pressure points and in the pressure itself can be tolerated. At least 10 single measurements	at least every 10,000 m²	Requirement defined in certification document
9.2	Tensile tests	DIN EN ISO 527-3; Table 2, No. 2.2; Crosshead speed: 100 mm / min, one sample each in MD and CMD from the edge zone and the middle of a smooth geomembrane, or the smooth edge zone of a textured geomembrane	at least every 10,000 m²	Requirement defined in certification document
9.3	Melt flow rate (MFR)	Table 1 No. 1.8; Samples from the geomembrane	at least every 10,000 m²	Requirement defined in certification document
9.4	Density	DIN ISO 1183-1; Samples from the geomembrane	at least every 10,000 m²	Requirement defined in certification document
9.5	Dimensional change after storage at elevated temperature	DIN EN 1107-2; Table 1 No. 1.9; Samples taken from the edge zones and the middle of the geomembrane, and from other critical areas (e.g. transition between smooth and textured areas)	at least every 5,000 m²	Table 1 No. 1.9 Table 4 No. 4.2

9. List of Standards, Directives, Advisory Guidelines, and Recommendations

The currently valid version of the standard is applicable.

ASTM D 1434:1998	Determination of the gas permeability of plastic films
ASTM D 1603:2006	Standard Test Method for Carbon Black In Olefin Plastics
ASTM D 4218:2008	Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds By the Muffle-Furnace Technique
ASTM D 5199:2001	Standard Test Method for Measuring the Nominal Thickness of Geosynthetics
ASTM D 5397:2012	Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
ASTM D 5596:2009	Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
ASTM D 5721:2013	Standard Practice for Air-Oven Aging of Polyolefin Geomembranes
DIN 16726:1986	Plastic roof sheeting; Plastic liners, Tests
DIN 16887:1990	Testing of pipes made of thermoplastics; Determination of stress-rupture behavior under internal pressure
DIN 18200:2000	Assessment of conformity for construction products - Certification of construction products by certification body – factory production control, third-party inspection and certification of products
DIN 53370:2006	Testing of plastics films - Determination of the thickness by mechanical scanning
DIN 53441:1984	Stress-relaxation test
DIN 53532:1989	Testing of rubber and elastomers - Determination of the permeability of elastomer films for liquids
DIN 61551:2008	Geosynthetics – Determination of burst strength
DIN EN 495-5:2001	Flexible sheets for waterproofing - Determination of foldability at low temperature - Part 5: Plastic and rubber sheets for roof waterproofing
DIN EN 1107-2: 2001	Flexible sheets for waterproofing – Determination of dimensional stability – Part 2: Plastic and rubber sheets for roof waterproofing
DIN EN 1848-2: 2001	Flexible sheets for waterproofing – Determination of length, width, straightness and flatness - Part 2: Plastic and rubber sheets for roof waterproofing
DIN EN 1850-2: 2001	Flexible sheets for waterproofing – Determination of visbible defects – Part 2: Plastic and rubber sheets for roof waterproofing
DIN EN 10204:2005	Metallic products – Types of inspection documents
DIN EN 12099:1997	Plastics piping systems – Polyethylene piping materials and components - Determination of volatile content;
DIN EN 12224:2000	Geotextiles and geotextile-related products – Determination of the resistance to weathering
DIN EN 12225:2000	Geotextiles and geotextile-related products – Test methods for determining the microbiological resistance by a soil burial test
DIN EN 12691:2006	Flexible sheets for waterproofing – Bitumen, plastic and rubber sheets for roof waterproofing - Determination of resistance to impact
DIN EN 13493:2013	Geosynthetic barriers – Characteristics required for use in the construction of solid waste storage and disposal sites
DIN EN 14150:2006	Geosynthetic barriers – Determination of fluid permeability
DIN EN 14414:2004	Geosynthetics – Screening test method for determining chemical resistance for landfill applications
DIN EN 14415:2004	Geosynthetic barriers - Test method for determining the resistance to leaching
DIN EN 14575:2005	Geosynthetic barriers - Screening test method for determining the resistance to oxidation
DIN EN 14576:2005	Geosynthetics - Test method for the resistance of polymeric geosynthetic barriers to environmental stress cracking
DIN EN ISO 60: 2001	Plastics - Determination of apparent density of material that can be poured from a specified funnel (bulk density)
DIN EN ISO 527-3: 2003	Plastics -– Determination of tensile properties – Part 3: Test conditions for films and sheets

Continuation, List of Standards, Directives, Advisory Guidelines, and Recommendations

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 1167-1:2006	Thermoplastic pipes, fittings and assemblies for the conveyance of fluids - Determination of the resistance to internal pressure – Part 1: General method
DIN EN ISO 1167-2:2006	Thermoplastic pipes, fittings and assemblies for the conveyance of fluids - Determination of the resistance to internal pressure – Part 2: Preparation of pipe test pieces
DIN EN ISO 1872-1:1999	Plastics – Polyethylene (PE) molding and extrusion materials – Part 1: Designation system and basis for specifications
DIN EN ISO 1183-1:2013	Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pyknometer method and titration method
DIN EN ISO 9001:2008	Quality Management Systems – Requirements (ISO 9001: 2008);
DIN EN ISO 9080:2013	Plastic piping and ducting systems - Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation
DIN EN ISO 9863-1:2005	Geosynthetics – Determination of thickness at specified pressures – Part 1: Single layers
DIN EN ISO 11358:1997	Plastics – Thermogravimetry (TG) of polymers - General principles
DIN EN ISO 12236:2006	Geosynthetics – Static puncture test (CBR test)
DIN EN ISO 12957-1:2005	Geosynthetics – Determination of friction properties – Part 1: Shear-box test
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
DIN EN ISO/IEC 17025 Corrigenda 2:2007	General requirements for the competence of testing and calibration laboratories
DVS 2211:2005	Welding of thermoplastics - Welding fillers - Marking, requirements and tests
DVS 2203-4:1997	Testing of welded joints of thermoplastic sheets and pipes– Tensile creep-rupture test
DVS 2207-1:2005	DVS 2207-1 Welding of thermoplastics - Heated tool welding of pipes, pipeline components and sheets made of HDPE
DVS 2225-4:2006	Welding of geomembranes made of polyethylene (PE) for the sealing of landfills and contaminated sites
DVS 2226-1:2000	Testing of fused joints on liners of polymer materials – Testing procedure, requirements
DVS 2226-2:1997	Testing of fused joints on liners of polymer materials – Lap shear test
DVS 2226-3:1997	Testing of fused joints on liners of polymer materials – Peel test
E DIN EN 1849-2:2009	Flexible sheets for waterproofing – Determination of thickness and mass per unit area - Part 2: Plastic and rubber sheets for roof waterproofing
FLL Guidelines:1995	Guidelines for the design, execution and maintenance of green roofs
GDA E 2-7:2008	Sliding stability of the sealing systems
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 5-1:1997	Principles of quality management
ISO 34-1:2004	Elastomers or thermoplastic elastomers – Determination of tear-propagation strength – Part 1: Trouser-, angle- and crescent-shaped test pieces
ISO 188:2011	Rubber, vulcanized or thermoplastic - Accelerated ageing and heat resistance tests
ISO 11357-6:2013	Plastics – Differential scanning calorimetry (DSC) – Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)
ISO 18553:2002	Methods for the assessment of the degree of pigment or carbon black dispersion in polyolefin pipes, fittings and compounds

10. 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 and sales partners where appropriate
Annex 3: Description of the production process
Annex 4: Manufacturer's raw-material declaration (resin type, carbon-black percentage, use of process recycled material)
Annex 5: Description of construction and arrangement of the marking
Annex 6: Description of the position of markings on the geomembrane
Annex 7: Description of quality control measures
a) In-house inspection
b) Third-party inspection
Annex 8: Manufacturer's storage and transport instructions
Annex 9: Description of the role labels
Annex 10: Description of the texture(s) of the geomembrane

State codes

(from Bundesarbeitsblatt (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 notified bodies[15] for suitability testing and quality control of production of waterproofing membranes:

SKZ – Testing GmbH
Tel.: 0931 4104-259, Fax: 0931 4104-207
Tel.: 0931 4104-170, Fax: 0931 4104-207
Friedrich-Bergius-Ring 22
97076 Würzburg

State Materials Testing Institute Darmstadt
Center for Construction Materials
Plastics Section
Tel.: 06151 16-4804, Fax: 06151 16-5658
Grafenstr. 2
64283 Darmstadt

[15] ISO 17025 accredited testing bodies and ISO 17020 accredited inspection bodies with respect to this Guidelines.