Federal Institute for
Materials Research
and Testing

Certification Guidelines for Plastic Geomembranes Used to Line Landfills and Contaminated Sites

Editor: W. W. Müller
Published by Laboratory IV.32, Landfill Engineering
English Translation of the Second Revised Edition, 09/99

Federal Institute for Materials Research and Testing (BAM)

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Translated by D. Etter

The complete text of the Certification Guidelines and the listing of certified geomembranes and protective layers can be found in either of the following WWW addresses: *bam.de\deponietechnik.htm* (WWW address of BAM) and *deponie-stief.de* (WWW address with extensive information on landfill technology). The address *akgws.de* (WWW address of the AK GWS industry association) provides information on certified geomembrane manufacturers and installers.

Introduction to Second Edition

The first Certification Guidelines for Plastic Geomembranes were published by the Landfill Engineering Laboratory of the Federal Institute for Materials Research and Testing (German acronym: BAM) in 1992. The Guidelines contributed to optimization of installation procedures and establishment of high quality standards for composite liner systems. A great number of successful lining systems have been realised since that time. Today the preparation work, process technology and equipment, sequential installation planning and quality management measures required to ensure composite liner systems meeting the most stringent requirements are known in detail. The resulting liner system is a technically mature and highly effective solution for base lining of landfills. Plastic geomembranes are also well suited for use in cap liners due to their excellent performance properties. In this sector they can be used in composite liner systems (Technical Directive Waste, Technical Directive Municipal Waste, Landfill Class II) or, e.g. when used to line contaminated land, can be used either alone or in conjunction with other components such as GCL's or capillary barriers. The BAM certification procedure has contributed significantly to the success of plastic geomembranes in this wide range of application sectors.

Plastic geomembranes used in landfill liners must be carefully selected to ensure long-term function long beyond their operative and post-operative control phases. For this reason German federal (TD Municipal Waste, TD Waste) and state regulations call for evaluation of suitability by certification of the plastic geomembranes and jointing technology used. Using these waste disposal regulations as a basis, the BAM landfill engineering laboratory in conjunction with its Advisory Council has created a certification system which is subject to constant refinement. In recent years changes and additions to the certification system have been implemented in conjunction with the Advisory Council, including requirements for textured geomembranes, protective layers, installation contractors and third-party inspectors. This revised second edition of the BAM certification guidelines includes these modifications.

The basic premise of the guidelines however remained unchanged: evaluation of suitability for use in a landfill liner must not be limited to the plastic geomembrane as such. The evaluation must also take into account the functional interaction of this single component with the overall system. Along with resin and production process specifications (which are required to withstand the complex stressing modes found in landfills and contaminated sites), quality control measures must also be specified to ensure workmanlike installation, effective quality assurance and workmanlike placement of protective layers. BAM certifications are now recognised and used by all German federal states as proof of suitability in accordance with the state of the art. For applicant firms this means that the cost and effort associated with geomembrane certification are compensated by the benefit of commercial access to the entire sector of municipal and industrial waste landfills and contaminated site lining.

This revised second edition of the Guidelines gives the requirements for BAM certification as they have evolved from certification practise to date and as dictated by the state of the art. The requirements have been formulated as concisely as possible. On the other hand, conformance with existing standards, guidelines and regulations was strived for when not in conflict with established quality standards. The requirements for protective layers will be defined in separate certification guidelines.

The accepted state-of-the-art resins for plastic geomembranes, certain grades of low-pressure polymerized polyethylene with carbon black UV stabilization, have been established for many years and their utilization was presumed in the certification requirements. However the requirements can be applied in an analogous manner to other materials as well.

On occasion the use of geomembranes made from recycled resin materials has been called for in cap

liner applications due to the reduced level of chemical attack encountered here. While justified from the point of view of waste material utilization, this would conflict with the need for defined and predictable performance as evaluated by long-term performance testing, which is a crucial part of all certification procedures. Accordingly, the recycled resin materials currently available are not suitable for use.

The BAM certification requirements are by no means "irrevocable"; on the contrary they must be revised in accordance with progress in the state of the art. These revisions are carried out in conjunction with the Advisory Council, a working committee which advises BAM in certification matters. The Advisory Council is chaired by a representative from the German Federal Environmental Ministry and is made up of members from resin manufacturers, geomembrane manufacturers, installation contractors, consulting engineers and testing institutes involved in design and third-party control, state authorities and BAM. The diverse nature of this forum is intended to promote acceptance of novel, economically attractive and technically secure solutions in the landfill lining industry.

The following Advisory Council members and guests participated in the consultations: Dipl.-Ing. K.-H. Albers, *Naue-ITB (Isolierungsgesellschaft für Tunnel und Bauwerke) GmbH*, Ing. K. Bohaty, *AGRU Kunststofftechnik GmbH*, Dipl.-Ing. W. Bräcker, *Lower Saxon State Bureau for Ecology*, Dr. B. Engelmann, *Federal Environmental Ministry*, B.S.Ch.Eng. D. Etter, *GSE Lining Technology GmbH*, Dipl.-Ing. L. Glück, *South German Plastics Center (SKZ)*, Herr R. Hartmann, *FUB Gesellschaft für Folientechnik und Bautenschutz mbH*, Dr. G. Heerten, *Naue Fasertechnik GmbH & Co KG*, Dipl.-Ing. G. Heimer, *State Material Testing Institute of Darmstadt*, Dipl.-Ing. A. Hutten, *DSM Polyolefine GmbH*, Dipl.-Ing. W. Karczmarzyk, *Ingenieurbüro Wersche GmbH*, Dr. F. W. Knipschild, *Ingenieurbüro und Prüflabor für Kunststofftechnik im Bauwesen*, Dr. G. Koch, *formerly of Hoechst AG*, Dipl.-Ing. B. Kopp, *Naue-ITB (Isolierungsgesellschaft für Tunnel und Bauwerke) GmbH*, Dr. G. Lüders, *BAM*, Dr. W. Müller, *BAM*, Ms. Dipl.-Ing. V. Olischläger, *Naue Fasertechnik GmbH & Co. KG*, Dipl.-Ing. R. Preuschmann, *BAM*, Dipl.-Ing. W. Quack, *Dow Deutschland Inc*., Dr. F. Sänger, *Ingenieurgesellschaft für Wasser und Tiefbau mbH*, Dipl.-Ing. R. Schicketanz, *Ingenieurbüro Schicketanz*, Dr. S. Seeger, *BAM*, Dipl.-Ing. E. Spitz, *Hermann Stumpp GmbH & Co KG*.

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The English translation was done by D. Etter.

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1 Legal Basis, Area of Validity and Regulations

The avoidance, utilization and disposal of waste materials is governed by applicable federal laws. The Waste Act (Section 4 Par. 5 AbfG) of 27 August 1986 and the Recycling and Waste Act of 27 September 1994 (Section 6 Par. 2, Section 12 Par.2 KrW-/AbfG), which now has come into effect, specify the enabling standards for the issuance of statutory orders and general administrative regulations. Section 12 Par. 2 of the KrW-/AbfG (previously Section 4 Par. 5 AbfG) provides the legal basis for the Second General Administrative Regulation for the Waste Act (TD Waste) and the Third General Administrative Regulation for the Waste Act (TD Municipal Waste). These two administrative regulations were issued primarily to regulate landfill construction uniformly throughout Germany for industrial and municipal wastes.

Subsection 10.4.1.1, Paragraph 4 of TD Municipal Waste specifies use of certified plastic geo-membranes only. Appendix E of TD Waste, which is also referenced in TD Municipal Waste, states that the proof of suitability of the plastic geomembranes must be furnished by means of a certification document. Both TD Waste and TD Municipal Waste specify BAM as a suitable certification authority for plastic geomembranes.
In accordance with this legal basis and the technical basis specified in the following text, BAM tests the suitability of plastic geomembranes and if applicable the jointing technology as applied for by the manufacturer and documents the suitability in a certification document.

Landfill liner systems must be constructed in accordance with the state of the art. These Certification Guidelines describe the requirements that must be fulfilled in installation of certified plastic geomembranes to provide a state-of-the-art liner system. These requirements are also referred to expressly in the certification document. The approving authorities of the states must see to it that these references are included in the landfill permit, therefore making them legally binding. This is a prerequisite for use of BAM certification as proof of suitability of the geomembrane-based liner system.

BAM when issuing certifications expressly reserves the right of revocation. Grounds for revocation are given if the manufacturer deviates from the procedures specified in the test reports and appendices of the certification document, the raw materials as used in the sample tested or other requirements specified in the certification document. Should that be the case, further production of these geomembranes identified with the BAM certification number is prohibited.

Changes in either the raw material or production process of the plastic geomembrane or dispositions for in-house quality control and third-party inspection of production require new certification. If installation and welding equipment used by the manufacturer and installation contractor proves substandard as shown by new technical findings, i.e. if the technical situation (state of the art) and the legal situation have changed such that issuance of certification would no longer be possible, this as well is grounds for revocation.

In the event of revocation the manufacturer is obligated to immediately return the certification document to BAM.

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

1. The Act for Avoidance, Utilization and Disposal of Waste Materials (Recycling and Waste Act - KrW/AbfG) of 27 September 1994, Bundesgesetzblatt I, p. 2705, 1994

2. The Third General Administrative Regulation for the Waste Act (TD Municipal Waste), Technical Directive for Utilization, Treatment and Other Disposal of Municipal Waste of 14 May 1993, Bundesanzeiger No. 99a, 1993.

Information for the implementation of TD Municipal Waste is given in:

2.1 Requirements for Municipal Waste Landfills in Lower Saxony, Landfill Manual, published by the Lower Saxon State Bureau for Ecology, Hildesheim, 1994.

2.2 Notice Concerning the Application of TD Waste to Landfills, Notice No. 12, published by the State Environmental Ministry of North Rhine-Westphalia, 1998.

3. The Second General Administrative Regulation for the Waste Act (TD Waste, Part 1), Technical Directive Concerning Storage, Chemical/Physical and Biological Treatment, Incineration and Disposal of Waste Materials Requiring Special Control of 12 March 1991, Joint Ministerial Gazette No. 8, p. 139, 1991.

4. Administrative Regulations of the Thuringian Ministry for Environment and State Planning - Controlled Waste Disposal – of 11.09.1992, Thuringian State Gazette No. 40, p. 1344, 1992.

5. Certification Guidelines for Plastic Geomembranes Used to Line Landfills and Contaminated Sites, Federal Institute for Materials Research and Testing (BAM), September 1999.

6. Requirements for Protective Layers Over Geomembranes in Composite Liner Systems, Certification Guidelines for Protective Layers, Federal Institute for Materials Research and Testing (BAM), August 1995.

7. Third-Party Inspection of Installation of Plastic Components in Landfill Lining Systems, Guidelines of the Federal Institute for Materials Research and Testing (BAM) Concerning Requirements for Qualification and Activities of Third-Party Inspectors, August 1998.

For further information and updates on the above documents as well as for a list of BAM-certified geomembranes and third party inspectors, see our home page: www. bam.de\deponietechnik.htm.

2 Objects Certified

2.1 General Information

The objects certified are plastic geomembranes used in base and cap liners of landfills and for containment of contaminated sites.[1]

The geomembranes are described by explicit specifications in the certification document covering the resin used in production, dimensions, surface texturing and the production process. The geomembranes must carry identification markings and incorporate protective strips on their edges. The geomembranes must fulfil the requirements given in these guidelines and their production must be subject to in-house quality control and third-party inspection within the framework of a quality management system.
BAM must be notified of and approve of any changes in the above. Should the manufacturer not notify BAM of such changes, the certification becomes invalid.

2.2 Resin

The manufacturer is obligated to explicitly identify in writing the resin used in geomembrane production.

Both pre-compounded resins and resins requiring addition of masterbatch in geomembrane manufacturing can be used. The masterbatch employed must be approved by the manufacturer of the base polymer. The manufacturers of the base polymer and the carbon black batch must contractually commit to notify BAM in due time of any change in the formulation of products supplied.

The batch shall incorporate a tracer additive defined in conjunction with BAM to ensure clear identification in the geomembrane.

When applying for certification of the geomembrane, the manufacturer must submit data sheets on the resins and additives employed containing at least the following information:

[1] referred to hereinafter as geomembranes

1. Resin type, in the case of HDPE in accordance with DIN 16776-1, and exact description and weight percentage of the additives
2. Molecular weight distribution
3. Specification of properties given in Table 5

This data will be confirmed by BAM by direct contact with the resin and batch manufacturers. The descriptions and weight percentages of the additives, molecular weight distributions and all other special data concerning resins and batches, i.e. the complete formulation, will be treated confidentially by BAM.

The content of recycled material from the production process (e.g. from edge trimming) may not exceed 5 wt %. The maximum permissible content will be specified in the certification document.

Use of regenerated resins, e.g. post-consumer scrap, is not permitted.

2.3 Dimensions

The maximum length per geomembrane roll and the width and thickness will be given in the certification document. The specifications for nominal, average and individual thickness values are given in Table 1. A basic requirement is that the minimum thickness must be at least 2.50 mm regardless of whether the geomembrane is smooth or textured. The minimum permissible width of the geomembrane is 4.5 m.

2.4 Surface Texturing

Geomembranes may incorporate texturing 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 have clearly visible permanent identification markings approximately every 2 m^2. The identification markings must contain the following information which may be encoded if necessary:

XX/BAMOU/YY/ZZ/Manufacturer's Logo/Thickness/Width/Resin/Type of Surface/Week of Manufacture/Year of Manufacture

OU is the organizational unit of BAM issuing the certification, XX is the federal state code and ZZ is the year of issuance of the certification.

The geomembranes must incorporate a 15 cm protective strip in the smooth land area to protect against surface contamination. The protective strip is applied in production. Adhesion must be sufficient to prevent separation during transport and site handling but must not leave residues on the surface of the geomembrane when removed.

2.6 Manufacturing Process and Site

The manufacturing site and a detailed description of the manufacturing process are fixed as described in the certification document. If requested by the applicant firm, any details concerning their manufacturing process will be treated confidentially by BAM.

Prior to issuing certification, BAM will visit the manufacturing site to verify the information provided on the manufacturing process and machines. BAM also checks that qualified personnel, machines, buildings, equipment for resin (base polymer and batch) storage and handling, testing machines and other equipment are such as to ensure satisfactory production and in-house QC in accordance with the requirements of Tables 5 and 6.

The manufacturer must demonstrate how his manufacturing process prevents defective production (e.g. due to moisture in resin[2], thickness

[2] Batches containing carbon black are particularly hygroscopic. Storage of such materials in dry areas or in closed bags is not sufficient to prevent moisture absorption. Therefore predrying for example by a continuous-operation dry air dryer is required or e.g. a degasification zone must be present on the extruder.

variations, surface damage[3]) by manufacturing procedures and quality management.

2.7 Jointing Technology

Jointing of the geomembranes at the site must be done exclusively by welding. They must be placed with sufficient overlap and joined 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 BAM.

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 in the certification document. Geomembrane manufacturers which themselves do not sell geomembranes must designate at least one sales representative. The sales representative must provide documentation of their capability and experience (e.g. training and experience of personnel, references) in the plastics and landfill sectors.

4 Testing Procedures and Equipment

Testing is carried out by BAM in Laboratory IV.32, Landfill Engineering and in BAM-approved test institutions (see Section 10). The Landfill Engineering Laboratory provides supplementary information on tests which are not defined or insufficiently defined by test standards.[4]

The minimum values given in the specification tables refer to the average value minus the standard deviation unless otherwise specified.

The test procedures and requirements given in the requirement tables refer normally to geomembranes made from medium to high density polyethylene resins in accordance with DIN 16776-1, EACL 35 - 40, T 006 to 022 (HDPE geomembranes), i.e. with a density (without carbon black) between 0.932 and 0.942 g/cm^3 and MFR values (190 °C/5 kg) between 0.4 and 3 g/10 min. Testing of geomembranes made from other resins will be based on the specifications of the requirement tables. For geomembranes made from HDPE, BAM may waive the need for the following tests in certification: Table 1, 1.10, Table 2, 2.6, Table 3, 3.6, 3.7 and 3.8.

The property values determined in the suitability testing of the geomembranes and tested in in-house QC and third-party inspection are given in Appendix 1 of the certification report.

In substantiated individual cases BAM may make special regulations which supplement or vary from the technical requirements defined in these guidelines. These special technical requirements will be drawn up following 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 average), change in melt flow rate due to processing, dimensional stability, 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 geomembranes. The following

[3] Damage of this type can occur for instance in application of texturing particles.

[4] "Supplementary Information on Tests for Certification of Plastic Geomembranes for Landfill Liners" is available from the Landfill Engineering Laboratory, IV.32, BAM, D-12200 Berlin/Germany.

properties are determined: behaviour under uniaxial and multiaxial deformation, tear resistance, static puncture resistance, dynamic puncture resistance (falling dart test), low-temperature behaviour (cryogenic flex), relaxation behaviour and weld seam quality as determined in short-term testing at installation sites.

4.3 Requirements for Physical Resistance and Long-Term Behaviour

Table 3, Requirements for Physical Resistance and Long-Term Behaviour, lists the properties, tests and requirements for the individual test attributes which characterize geomembranes' resistance to chemicals, stress cracking, thermooxidative degradation, weathering, microbe attack, root penetration and long-term combined stressing. These factors comprise all significant attack processes to polyolefinic materials. Prediction of expected service life is done on the basis of time-to-failure curves from long-term burst tests conducted on pipe specimens extruded or otherwise fabricated from the resin used to make the geomembranes. However, alternative test procedures and requirements to long-term pipe burst testing are being developed to allow quicker evaluation of resins for which long-term pipe burst test data is not available. The test procedures under consideration in this regard are stress cracking of notched specimens under constant tensile loading and oxidative stability under immersion in hot water. The performance requirements in these tests will be based on the performance of geomembrane resins which have proven suitable in long-term pipe burst testing.

In addition a new test procedure has been introduced for characterization of the welding properties of various resins.

4.4 Requirements for Textured Geomembranes

Requirements for textured geomembranes and for the resin making up the texturing depend on the type of texturing and the fabrication procedure employed. A test procedure (long-term shear test) is currently being analyzed for evaluation of long-term properties of texturing particles and therefore their ability to bear long-term shear force. When these trials are completed, the requirements in Section 4.4.1 below for texturing resins will be redefined.

4.4.1 Texturing Resins

Texturing material or laminates applied subsequent to production must be made of the resin used to fabricate the base geomembrane or of another resin which has been used in certified geomembranes. Processing of the resin in the texture application process must not cause any alterations which impair long-term properties, in particular with regard to molecular structure (melt flow rate) or oxidative stabilty (OIT time). 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.

Bonding 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 have come about from fused interfaces. Auxiliary materials, e.g. adhesives, are not permitted.

In general the properties of textured geomembranes may not change detrimentally as compared to those of smooth geomembranes (see Tables 1, 2 and 3) apart from two exceptions as given in Table 4: elongation at break in the textured areas and dimensional stability of embossed textured geomembranes. In particular the yield strength and elongation at yield in uniaxial tensile testing and the bulge elongation in multiaxial tensile testing of specimens taken from the textured areas must fulfil 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. elongation at break, yield strength and elongation at yield in the untextured land areas must correspond to those of the smooth geomembrane.

The test procedures given in Table 3 are normally not required for textured geomembranes if a certi-

fied smooth geomembrane is made on the same production line from the resin used to make the textured geomembrane.

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

QC of incoming raw materials along with regular in-house production QC and third-party inspection must be provided for to ensure consistent quality in geomembrane manufacturing. These activities must be conducted in accordance with DIN EN ISO 9002 to ensure a quality management system for geomembrane manufacturing as described in e.g. the DIN standard series DIN EN ISO 9000-1 through DIN EN ISO 9004-1. The manufacturer's quality management manual must be submitted to BAM as part of the documentation required for certification.

The specifications for the resin or base polymer and carbon black batch are agreed on jointly by the manufacturers of the resin or base polymer and batch and the geomembrane manufacturer. The specifications for density, melt flow rate and carbon black content of the resin or carbon black batch are entered as such in the certification document. This agreement must also provide for acceptance test certificates on the basis of DIN EN 10204, Section 3.1B. 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, carbon black content of batch and moisture content. The test procedures required and their frequencies are given in Table 5.

The test attributes given in Table 6 must be tested in in-house manufacturing QC using the procedures and frequencies given in the table. The test data generated both in in-house QC and in the third-party inspection described below must fulfil the requirements and tolerances of the requirement tables and Appendix 1 of the certification document. The test data must be archived for 20 years from the date of testing such as to provide traceability of the test results for any given geomembrane roll. This test data must be made available to BAM upon request. Each geomembrane roll must be identified by a printed identification code as defined in the certification document applied prior to shipment in a clearly visible location.

An acceptance test certificate must be issued for each roll shipment on the basis of DIN EN 10204, Section 3.1B. The acceptance test certificate must clearly identify the specific rolls of those shipped on which the test data given was actually determined and which data apply for other rolls in the production sequence due to low test frequency (see Table 6). QC data given in this manner must be provided for all rolls identified and supplied as BAM-certified geomembranes.

Manufacturing of the geomembranes must be subject to inspection by a third-party institute approved by BAM. This institute must have sufficiently qualified personnel, the necessary test equipment, fulfil the requirements of the DIN EN ISO 17025 standard and be approved by BAM as a third-party inspector. A prerequisite for this approval is accreditation for the standard tests conducted in third-party inspection. The inspection contract between the third-party inspector and the geomembrane manufacturer must be submitted to BAM as part of the documentation required for 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 inspection and the geomembrane manufacturer. The inspection contract must meet the following requirements:

1. When sampling the initial production of certified geomembranes, the third-party inspector must check that prerequisites are fulfilled for proper manufacturing and in-house QC.
2. In third-party inspection all tests given in Table 7 must be carried out on the precompounded resin

[5] In-house quality control is now referred to in the construction sector as "supplier's fabrication control" (as per draft of new DIN 18200 standard).

(or base polymer and batch) and the geomembranes. Inspections of the laboratory and production must be included as well along with a check on in-house QC records to monitor the QC system and its extent.

3. The third-party inspection must be carried out 2 times per year. If the manufacturer produces both certified smooth geomembranes and certified one or two-sided textured geomembrane, third-party inspection will be carried out 2 times per year on each, i.e. on the product group "smooth geomembranes" as well as on the product group "textured geomembranes". The material samples for the tests must be taken by the third-party inspector directly from production.

The inspection visits must normally be unannounced. They must coincide with production of geomembranes which are intended for use as certified geomembranes and carry the printed I.D. code given in the BAM certification. The geomembrane manufacturer must therefore provide the third-party inspector production plans for all BAM-certified geomembrane in due time to permit proper scheduling of inspection visits. Proof of completed third-party inspection will be furnished by inspection reports which the inspection institute will provide regularly and of their own accord to BAM. This must be stipulated in the inspection contract. In the event deficiencies are discovered, the inspection institute will decide on the necessary measures to be taken. Should repeated or serious deficiencies be discovered, the inspection institute must inform BAM accordingly.

6 Installation Requirements

6.1 General Information

Landfill liner systems must be fabricated in accordance with the state of the art. The geomembranes used must be certified for this application sector. Geomembranes are installed in accordance with the state of the art only if the following requirements[6] are met and stipulated in the landfill permit. This is a prerequisite for the use of BAM certification as proof of suitability and utility. This section of the guidelines is therefore of particular interest to approval authorities.

Fulfilment of the requirements must be verified by self-inspection[7] on the part of the installation contractor, by third-party inspection - e.g. by an independent outside engineering consultant or test institute, as directed by the approval authority - and by inspection (normally without need for further testing) on the part of the approval authority.

In order to ensure definition of quality characteristics in accordance with the materials employed and the state of the art, the requirements must be taken into account in planning as well as in compilation of the bidding specifications and the quality assurance plan. Participation of the third-party inspection institute is therefore required starting with the planning stage.

The requirements apply in general to installation of geomembranes. When used in base liner systems, the geomembranes are usually employed as part of a composite liner system, i.e. over a clay liner. When used in cap liner systems, geomembranes are employed as part of a composite liner system, a modified composite liner system in which the clay liner is replaced by a GCL, liner systems comprising geomembranes installed in conjunction with a capillary barrier and lining systems comprising only geomembranes.

When geomembranes are installed as part of a 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 clay liner. This smooth configuration, also referred to as intimate contact, prevents spreading of leakage from possible holes or damage between the two

[6] See in addition Appendix E of TD Waste and TD Municipal Waste.

[7] These terms are used as defined in TD Municipal Waste, Section 10.4.1.2. The term self-inspection is sometimes incorrectly interpreted as meaning self-inspection on the part of the owner by a designated third party.

liners, therefore ensuring the redundancy which is strived for in a composite liner system. In other cases, e.g. when the geomembranes are installed over a levelling 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 elongation of HDPE geomembranes under multiaxial loading at 40 °C is 3 %, while the limit under multiaxial loading at 20 °C is 6 %.

6.2 Requirements for Installation Contractors

The geomembranes must be installed by a specialist firm using personnel with proven experience and qualifications equipped with the necessary machinery and other devices. The requirements for installation contractors are described in BAM recommendations entitled "Installation Contractors for Installation of Plastic Components in Landfill Lining Systems". Proof of the required qualifications, equipment and experience can be established e.g. by inspection by a quality supervisory society of an industrial association demanding full compliance with the requirements of the BAM recommendations and inspection by an independent test institute recognized for its expertise and experience.[8]

6.3 Self-Testing and Third-Party Inspection

Fabrication of the liner system must be carried out according to a quality assurance plan defining the responsibilities, equipment and actions required for verifiable attainment of the required quality characteristics. 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 appendices. The quality assurance plan must provide for coordinated action between the installation contractor and all other parties at the site involved in multisequential construction processes, e.g. fabrication of the composite liner system. Self-testing by the installation contractor and third-party inspection in installation of the geomembranes must be included in the quality assurance plan.

The installation contractor must have a foreman who is experienced in installation and is responsible for self-testing present at the site at all times during 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 fulflled with regard to the qualifications and responsibilities of the third-party inspector are described in the BAM Guideline entitled "Third-Party Inspection in Installation of Plastic Components in Landfill Liner Systems". The commission for the third-party inspector is given either by the owner with the consent of the approval authorities or directly by the approval authorities. The approval authorities must be kept advised of and be able to provide input to the third-party inspection as it progresses.

6.4 Information on Planning

The soil base must be sufficiently firm such that compression from weights bearing above will not cause damage to the lining system. Deformation resulting from such settlement must not exceed the permissible deformation of the geomembrane.

Calculation of static stability of the liner system during construction, eventual intermediate states and its final state should be conducted according to accepted procedures, e.g. GDA recommendations[9] E-2-7 "Shear Resistance of Lining Systems"[10],

[8] The German industrial association of geomembrane manufacturers and installers, Arbeitskreis Grundwasserschutz e.V. (AK GWS), has established a quality supervision system of this type based on the BAM recommendations. The quality supervision is realised by auditing and inspection of installation contractors by BAM. Installation contractors maintain their AK-GWS approved status only if they fulfil the requirements of the recommendations.

[9] These recommendations are available from the German Geotechnical Society, Essen, Germany (www.dggt.de).

[10] Bautechnik 75, 1998, Volume 9.

E 2-21 "Calculation of Spreading Stability and Estimated Deformation on Landfill Bases" and E 3-8 "Frictional Behaviour of Geosynthetics"[11]. Dimensioning of any reinforcing elements required should be done in accordance with the GDA recommendation E 7-1 "Static Stability Calculations of Geosynthetic Reinforcing Components in Landfills"[11]. Geometric transitions such as embankment toes and heads must be executed in accordance with the DVS R 2225-4 Guidelines[12].

6.5 Support Surfaces for Geomembranes

Geomembranes may be installed only over suitable support layers. The support layer may also be designed to perform additional functions, i.e. that of an secondary sealing layer, capillary layer, base layer or gas collection layer. In composite liner systems the clay liner must meet special requirements as described in the following section. For all other support surfaces the requirements given in Section 6.5.2 apply.

6.5.1 Surface Requirements for Clay Liners

The surface of the clay liner must be such that it will not cause short-term or long-term mechanical damage to the geomembranes when joined 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 plastics. The approval authorities may wish to participate in this acceptance inspection and should be advised accordingly.

The surface is acceptable if it fulfils the following criteria:

Physical criteria: the surface must be stable bearing, homogeneous, finely grained and free of holes; it may not include particles greater than 10 mm in diameter or foreign matter; fine gravel particles must be suspended, i.e. embedded on all sides by cohesive material. The surface must be free of coarse particles and foreign material.

Geometrical criteria: the surface must in general be free of abrupt changes in height. Individual steps (differences in compression) are permissible up to 0.5 cm in height. Deviations from level under a 4 m lath (straight edge) may not exceed 2 cm.

Analysis of field trials may provide further project-relevant evaluation criteria.

6.5.2 Surface Requirements for Other Support Layers

The support layer may be made of noncohesive or weakly cohesive soil materials with a grain size range of 0 - 32 mm or of recycled materials such as building rubble, crushed glass or slag in the same grain size range. The geometric form, grain size and grain size distribution of support layer materials must be such as to exclude non-permissible mechanical stressing of the geomembrane. This must be verified for the project at hand by a modified plate bearing test[13] and selected stressing modes in the field test plot. The permissible mechanical stresses for geomembranes and the test procedures for the modified plate bearing test are given in the BAM Certification Guidelines entitled "Certification Guidelines for Protective Layers; Requirements for Protective Layers Over Geomembranes in Composite Liners". In modified composite systems incorporating GCL's in place of clay liners, the GCL provides mechanical protection under the low surface weights bearing on cap liner systems. This effect can be taken into account in

[11] Bautechnik 74, 1997, Volume 9.

[12] The DVS Guidelines are available from Deutscher Verband für Schweißen und Verwandte Verfahren e.V., Düsseldorf, Germany, (www.dvs-ev.de).

[13] *Seeger, S. and Müller, W.*: Limits of Stress and Strain: Design Criteria for Protective Layers for Geomembranes in Landfill Geomembrane Systems. In: Geosynthetics: Applications, Design and Construction, Proceedings of the First International European Geosynthetics Conference (Eurogeo 1). *DeGroot, M.B., DenHoedt, G., und Termaat, R.J.* (Hrsg.). Rotterdam: A. A. Balkema 1996 and
Seeger, S. and Müller, W.: Requirements and Testing of Protective Layer Systems for Geomembranes. Geotextiles and Geomembranes, 14(1996), H. 7-8, S. 365.

selection of support layer materials with regard to grain geometry, grain size and grain distribution.

The slopes and radii of curvature of the support layer must conform to those given in the QA plan. The measured height at any point may not deviate from specified height by more than 3 cm. Steps, compression marks and ridges may not be larger than 2 cm. Certain support layer 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. In modified liner systems incorporating GCL's in place of clay liners, the requirements for the support layer under the GCL must be met as given in the relevant guidelines, recommendations and construction-sector certifications.

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 assurance measures defined for the site must ensure that these instructions are followed.

Transport of geomembrane rolls to the site and on the site must be done only by the installation contractor or personnel trained by the installation contractor using suitable transport equipment (e.g. lifting traverse) in accordance with the transport instructions of the geomembrane manufacturer.

A acceptance certificate based on DIN EN 10204-3.1 (as described in Section 5) must be provided to the third-party inspector for each shipment along with the shipping documents.

Storage of the geomembrane rolls must be such as to prevent denting from stones, foreign material, support boards etc. as well as non-permissible deformation of the stacked rolls. A suitable storage area must be prepared at the site prior to delivery of the geomembrane rolls.

6.7 Installation

Before installation of the geomembrane rolls, the installation contractor and the third-party inspector must check that they fulfil the requirements of its certification document and the project specifications and that the geomembrane rolls are not damaged. During installation of the geomembrane rolls, a complete copy of the 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 approval authority. When installation is complete, the plan is modified as necessary, providing the final diagram of the installed liner system. Important principles to be followed in installation and connection to structural components are illustrated in the DVS R 2225-4 Guidelines. Normally the geomembrane must be included in the field test plot made for the clay liner in order to optimize installation with regard to the other liner system components. Handling of the rolls in installation must be done only by the installation contractor or personnel trained by the installation contractor using suitable transport equipment (e.g. lifting traverse) in accordance with the transport instructions of the geomembrane manufacturer. 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 configuration over the support layer after placement of the protective drainage layer. This requires correct timing of the installation work, i.e. utilization of daily temperature cycling (the coefficient of linear thermal expansion of HDPE geomembrane is $1.5 - 2.5 \cdot 10^{4}\ K^{-1}$ over a temperature range of 20 °C to 70 °C).

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 can not 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

[14] The magnitude of the strain is described in *Soong, T.-Y. and Koerner, R.*, Behavior of Waves in

sequence in placement of the protective layer and the drainage layer are particularly important in this regard. This therefore must be done in the presence of the third-party inspector.

Care must be taken that flow or accumulation of condensate under the geomembrane does not damage the clay liner, i.e. impair full-surface contact.

A special installation procedure known as "secured modular installation "has proven beneficial in this regard while still permitting fast installation rates, as described in[15].

Installation normally may not take place during precipitation of any kind or over areas with standing water. Welding is not permissible at ambient temperatures below the dew point. Large-area installation of geomembranes is normally only possible from April to October. Installation in other months is possible only under unseasonably favourable weather conditions. Protection against inclement weather (e.g. a tent or heated tent) is normally required. Installation outside of the period April to October may be done only with the consent of the approval authority and the third-party inspector.

Each geomembrane when installed is given an identification number in the final diagram of the installed liner system. These identification numbers, the identification markings and the manufacturer's roll numbers given in the shipping documents must provide full traceability of all geomembranes. 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 must be done in accordance with the DVS R 2225-4 Guidelines. A welding trial using the welding machines and equipment, sensors and testing equipment intended for subsequent use must be conducted in the presence of the third-party inspector before welding work begins or during construction of the field trial plot. Use of procedures, machines or equipment other than those used 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 welded together. Should welding of geomembranes made from two different resins be unavoidable, the two resins must either be in the same MFR group as defined in DIN 16776-1 or in the MFR groups 006 and 012.

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 seam samples made before welding or taken from either end of seams. 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. An acceptance test certificate based on DIN EN 10 204-2.3 is required for each shipment of extrudate resin to the site. It must provide the QC

High Density Polyethylene Geomembranes: a Laboratory Study. Geotextiles and Geomembranes 178 (1999) pp. 81-104.

[15] *Averesch, U.B. and Schicketanz, R*., Installation Procedure and Welding of Geomembranes in the Construction of Composite Landfill Geomembrane Systems – Focus on "Riegelbauweise". From Proceedings of the 6th International Conference on Geosynthetics, Atlanta, 1998, published by *Rowe, R.K.*, Industrial Fabrics Association, Rosewill, USA, 1998;
Corbet, S.P. und Peters, M.: First Germany/USA Geomembrane Workshop. Geotextiles and Geomembrane, 14(1996), H. 12, S. 647-726;
Dornbusch, J., Averesch, U. and El Khafif, M., Construction Procedures and Quality Management in Fabrication of Composite Liners for Landfills. Forschungsvereinigung Baumaschinen und Baubetrieb e.V., Aachen/Germany, 1996. This study was conducted as part of the BMBF Research Project entitled "Continuing Development of Landfill Liner Systems".

test results given in DVS M2211 determined by the extrudate manufacturer on this shipment. The test certificate must be provided to the third-party inspector along with the shipping papers.

6.9 Protective Layers

A protective layer is required between the geomembrane and the drainage layer (e.g. 16 – 32 mm gravel). Its purpose is to protect the geomembrane from puncture of any type during construction and subsequent operation of the landfill. The protective layer must be dimensioned to withstand the maximum load and temperature expected in operation. In addition, materials and design must be such that shear strength as required for static stability on slopes is not impaired by this loading.

Proof of suitability of protective layers with geotextile components must be furnished by means of a certification document in accordance with the BAM Guidelines entitled “Requirements for Protective Layers Over Geomembranes in Composite Liner Systems”. Geotextiles with lower area weights than those specified in Section 9 of these Certification Guidelines may be used in cap liner systems providing their protection efficiency satisfies the requirements of Section 5.3 of the certification guidelines for protective layers.
The installation contractor must normally place the protective layer each day following completion of the liner surface which was fabricated and smoothed out that day. The third-party inspector must verify that the installation and anchoring procedures for the protective and drainage layers will cause no damage to the geomembrane below.
Further requirements regarding protective layer installation are given in Section 10 of the certification guidelines for protective layers.

7. Changes, Period of Validity and Notification of Deficiencies

Should any changes occur in the objects certified, i.e. the resin, geomembrane dimensions, surface texturing, identification markings, place of manufacture, installation processes and jointing 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 of time. 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 then may not 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 in manufacture and installation of geomembranes and any geomembrane-related failures.

8. Requirement Tables

Table 1, Part 1: General Physical Requirements

	Properties	Test Attributes	Requirements	Tests/Test Conditions
1.1	Surface condition	Appearance	Smooth surface, free of fissures, craters and pores, no damage	Visual inspection in accordance with DIN 16726, Section 5.1
1.2	Homogeneity	Appearance of cross section	Free of pores, voids, foreign inclusions	
1.3	Carbon black content	Weight percentage	Range for nominal value specified in certification report: 1.8 – 2.6 wt %, individual values determined may not vary from nominal by more than ±10 %	Thermogravimetric analysis based on DIN EN ISO 11358, Section B1 in Supplemental Information on Tests[1], or determination in accordance with ASTM 1603-94
1.4	Carbon black distribution	Supplemental Information onTests[1]	Supplemental Information on Tests[1]	ASTM D5596-94, Section B2 in Supplemental Information on Tests[1]
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 ≤ 50 mm	Determination of skew and waviness in accordance with DIN 16726, Section 5.2
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 average thick-ness	Arithmetic average of thickness measurements must be ≥ nominal thickness	As called for in DIN 16726 Section 5.3, measure thickness in accordance with DIN 53370 every 0.2 m over the entire width of the geomembrane.
		Individual thickness measurements	The minimum permissible thickness is 2.50 mm. Therefore, for geomem-branes with a nominal thickness of 2.50 mm all individual measurements must be ≥ 2.50 mm and the maximum permissible deviation of any individual value from average is ± 0.15 mm. For other nominal thicknesses, maximum permissible deviation of any individual value from average is ± 0.20 mm	

[1]) The pamphlet entitled “Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners“ is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

Table 1, Part 2 General Physical Requirements

	Properties	Test Attributes	Requirements	Tests/Test Conditions
1.8	Melt flow rate	MFR of resin, MFR of geomembrane	$\lvert \delta MFR \rvert \leq 15$ %, $\lvert \delta MFR \rvert$: absolute value of difference in MFR between resin and geomembrane	DIN ISO 1133
1.9	Dimensional stability	Absolute value of shrinkage $\lvert \delta L \rvert$ of sides of square sample	$\lvert \delta L \rvert \leq 1.0$ % for all individual values	Oven curing and shrinkage determination based on DIN 16726, Section 5.13.1, DIN 53377 and draft DIN EN 495-1, Oven cure at (120±2)° C for 1 hour, shrinkage determination[1)] on 10 cm square specimens taken every 1.0 m over the width of the geomembrane. Measuring accuracy of the mechanical measuring gauge: at least 0.01 mm. Round off shrinkage value to nearest 0.1 %.
1.10	Permeabilty to hydrocarbons	Permeation rate of trichloroethylene at 23 °C	< 80 g/m²d, determined from the steady-state line	Steady-state determination at 23° C on specimens with 80 mm effective diameter and 2.5 mm thickness based on DIN 53532, Section B4 of Supplemental Information on Tests[1]
		Permeation rate of acetone at 23 °C	< 0.5 g/m²d, determined from the steady-state line	
1.11	Oxidative stability[2]	Oxidation Induction Time (OIT)	At 210 °C ≥ 20 min	Determination based on DIN EN 728, Section B5 of Supplemental Information on Tests[1]

[1]) The pamphlet entitled “Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners“ is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

[2]) The efficiency of antioxidants depends on temperature. An antioxidant which is highly effective at normal ambient temperatures may not be effective at the high temperatures used in the OIT procedure. This has been taken into account in the requirements given under points 1.11 and 3.3. Depending on the stabilization formulation used as disclosed to BAM, in certain cases other analytic procedures are required to determine the change in stabilization caused by immersion testing.

Table 2: Mechanical Requirements

	Properties	Test Attributes	Requirements	Tests/Test Conditions
2.1	Behaviour under multiaxial deformation	Bulge elongation ϵ_b in multiaxial tensile test	$\epsilon_b \geq 15$ %, without yielding	Based on DIN 53861-1 and ASTM D5617, see Section B6 of Supplemental Information on Tests[1]
2.2	Tensile properties	Yield strength σ_Y Elongation at yield ϵ_Y Elongation at break ϵ_B, in both extrusion and transverse directions	$\sigma_Y \geq 15$ N/mm^2 $\epsilon_Y \geq 10$ %, $\epsilon_B \geq 400$ %,	Tensile test in accordance with DIN EN ISO 527-3, test specimen type 5, (Specimen thickness need not be in conformance with this standard), 23° C / 50% R.H., crosshead speed 50 mm/min up to 20% elongation, thereafter 200 mm/min, 5 test specimens for each direction (extrusion and transverse) taken over the entire width of the geo-membrane
2.3	Tear resistance	Tear force	Tear force ≥ 500 N, Tear force ≥ 300 N	Tear test in accordance with DIN 53356-A, Tear test (Graves-type crescent specimen) DIN 53515, on specimens taken in extrusion and transverse directions
2.4	Resistance to static puncture	Puncture force	≥ 6000 N	Static puncture test DIN EN ISO 12236, crosshead speed 50 mm/min
2.5	Resistance to dynamic puncture	Water tightness at spot of puncture	No loss of water tightness	Test in accordance with DIN 16726, Section 5.12, drop height 2000 mm
2.6	Cold temperature brittleness (flexural)	Visual appearance of flex edge	No cracks	Flexural testing in accordance with DIN EN 1876-1, flex edge in extrusion and transverse directions
2.7	Relaxation behaviour	Stress as a function of time at constant strain (stress vs. time curve)	Stress at 1000 hours must be ≤ 50 % of stress at 1 minute	Stress relaxation test in accordance with DIN 53441, 3 % strain, 23 °C, 50 % R.H., specimens taken in extrusion and transverse directions
2.8	Seam quality	Deformation and failure behaviour under shear stress	No shear failure of seam, pronounced necking in parent material	Shear test according to DVS R 2226-2, crosshead speed 50 mm/min
		Deformation and failure behaviour under peel stress	No peeling of seam, pronounced necking in parent material	Peel test according to DVS R 2226-2, crosshead speed 50 mm/min

[1]) The pamphlet entitled “Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners“ is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

Table 3, Part 1: Requirements for Physical Resistance and Long-Term Behaviour

Nr.	Properties	Test Attributes	Requirements	Tests/Test Conditions
3.1	Resistance to chemicals (concentrated liquid solutions)[1]	Change in weight, change in yield strength and elongation at yield	Change in weight after redrying ≤ 10 % Change in yield strength and elongation at yield ≤ 10 %	Immersion testing on the basis of DIN ISO 175, see Section B9 of Supplemental Information on Tests[1]. Immersion temperature: 23 °C. Immersion must be over a period of 90 days or to attainment of steady-state weight, whichever occurs first. Tensile tests to be conducted on redried specimens.
3.2	Resistance to stress cracking	Time to failure in stress crack test	≥ 200 h at test stress equal to 30 % of the yield strength determined at 23 °C / 50 % R.H.	Notched constant tensile load test in accordance with ASTM D 5397, see Section B7 of Supplemental Information on Tests[2]
3.3	Resistance to thermal oxidative degradation in air	Change in appearance, relative change in elongation at break $\epsilon_{B,}$ OIT time after 1/2 year exposure: OIT(0.5 y) Relative change in OIT time: (OIT(0.5y)–OIT(1y))/ OIT(0.5y)	No change, see Table 1.1 No change beyond experimental uncertainty Average time ≥ 10 min ≤ 0.3 calculated from average values	Oven curing in forced-convection oven at 80 °C for 1 year, OIT determination based on DIN EN 728 and ASTM D 3895 at 210 °C in aluminium pan
3.4	Long-term behaviour under combined stressing[3]	Graph of time to failure vs. test stress in long-term pipe burst testing	Extrapolation (in accordance with the extrapolation time limitations given in DIN 16887) of time to failure vs. stress curves generated at high temperatures (e.g. 80 °C, 60 °C) must predict no failure after 50 years at a stress of 4 N/mm^2 and a temperature of 40 °C.	Long-term burst testing in accordance with DIN 16887 on pipe specimens extruded or otherwise fabricated from the resin used to make the geomembrane

[1)] Substances 2, 3, 6, 7, 10 and 11 need not be tested for HDPE geomembranes, see "Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners", which is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

[2)] The pamphlet entitled "Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners" is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

[3)] Service life prediction of HDPE geomembranes is based on extrapolation of long-term pipe burst test curves in accordance with DIN 16887 or ISO DIS 9080. The validity of this procedure is backed up by scientific studies and decades of experience. Pipe burst test curves are not required for resins for geomembranes if their stress-crack resistance has been shown to fulfil the requirements of point 3.2 above and their oxidative stability has been shown to fulfil the requirements of point 3.3 above in a test analogous to DIN 16887 pipe burst testing – i.e. involving immersion of geomembrane specimens in water at 80 °C for a period of at least 10^4 h (e.g. long-term tensile test).

Table 3, Part 2: Requirements for Physical Resistance and Long-Term Behaviour

	Properties	Test Attributes	Requirements	Tests/Test Conditions
3.6	Weathering resistance	Change in mechanical properties	Section B10 of Supplemental Information on Tests[1]	Section B10 of Supplemental Information on Tests[1]
3.7	Microbe resistance	Visual inspection, change in weight, change in mechanical properties	No substantial change in average values i.e., $\Delta w \leq 5$ %, $\Delta\epsilon$, $\Delta\sigma \leq 10$ %	DIN EN ISO 846, Procedure D, soil burial testing in microbe-active soil for 1 year, tensile testing in accordance with DIN ISO 527, see Table 2, 2.2
3.8	Root penetration resistance	Visual inspection	No penetration	FLL root penetration resistance procedure[2], from FLL Guidelines for Landscaped Roofs, tests on material with and without welding seams
3.9	Welding properties of resins[3]	Time to failure in long-term peel test	Geometric mean ≥ 35 h	Long-term peel testing based on DVS R 2203-4 and DVS R 2226-3 of overlap welds with test channels made with hot-wedge welding machine using welding parameters in optimum field, see Section B11 of Supplemental Information on Tests[1]

[1]) The pamphlet entitled "Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners" is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

[2]) FLL: Landscaping Research Society, Bonn/Germany. The FLL test procedure is currently being revised by CEN Technical Committee TC 254.

[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 parameter field which do not show times to failure typical of that resin are substandard even if their times to failure exceed 35 h.

Table 4: Additional Requirements for Textured Geomembranes

	Properties	Test Attributes	Requirements	Tests/Test Conditions
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, nominal minus 0.20 mm)	Measurement e.g. in accordance with ASTM D 5994-96, see Section B3 of Supplemental Information on Tests[1]
4.2	Dimensional stability	Absolute value of shrinkage $\lvert\delta L\rvert$ of sides of square sample	$\lvert\delta L\rvert \leq 1.50$ % for individual values of embossed texturing $\lvert\delta L\rvert \leq 1.00$ % for individual values of applied texturing	Table 1, 1.9
4.3	Mechanical properties of textured areas	Elongation at break ε_B	Requirement set for each case individually	Table 2, 2.2
4.4	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)
		Variation in friction parameters	No substantial additional variation in friction parameters beyond test repeatability	Shear-box testing of 30 cm x 30 cm specimens in accordance with GDA E 3-8
		Homogeneity of texturing appearance	Comparison with reference samples provided to BAM	Visual inspection
4.5	Texturing adhesion for applied texturing	Behaviour in shear-box test	No peel-off or removal of texturing	Shear-box testing under compressive loads typical of landfills in accordance with GDA E 3-8
		Scrape strength	Requirement set for each case individually	Test procedure of MPA Darmstadt, Section B13 of Supplemental Information on Tests[1].
		Time to failure in long-term shear test	Evaluation of time to failure based on DIN 16887	Long-term shear test, see Supplemental Information on Tests[1]
4.6	Chemical resistance of bonding of texturing applied after production	Change in scrape strength	Change in average value ≤ 10 %	Immersion in substances 5 and 9, see Table 3, 3.1. For scrape test procedure, see Section B12 of Supplemental Information on Tests[1]
4.7	Stress-crack resistance (long-term tensile test)	Time to failure	Geometric mean of times to failure ≥ 700 h	Long-term tensile test based on DVS R2203-4 on at least 5 test specimens at 80 °C und 4 N/mm² tensile stress in a 2 % surfactant solution, see Section B8 of Supplemental Information on Tests[1]

[1]) The pamphlet entitled "Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners" is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

Table 5: Test Procedures and Frequencies for Incoming Quality Control of Resin and Carbon Black Batch

	Test Attributes	Tests / Test Specimens	Frequency	Requirements and Tolerances
5.1	Density	DIN 53479, Procedure A / extrudate from MFR determination of resin or base polymer pellets	Random samples from every shipment	Requirement defined in certification report
5.2	Melt index MFR 190/5 or MFR 190/21.6	DIN ISO 1133 / resin 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 (see Supplemental Information) or determination by ASTM 1603-76 / batch pellets	Random samples from every shipment	Requirement defined in certification report
5.4	Weight percent volatiles, moisture	Weight loss in oven (DIN EN 12099 and R 14.3.1 TW) or in infrared oven / resin pellets or base polymer pellets and 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 % in batch
5.5	Bulk density[1]	DIN EN ISO 60 and DIN 53466/ base polymer pellets and 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]) Required only in the event volumetric batch metering is used.

Table 6, Part 1: Test Procedures and Frequencies for In-House Quality Control of Geomembranes by Manufacturer

	Test Attribute	Tests / Test Specimens	Frequency	Requirements and Tolerances
6.1	Thickness	Table 1, 1.7 / measured at a minimum of 10 different points across the width of the geomembrane	Continuous automatic monitoring[1] with mechanical control measurement every 300 m	Requirement defined in certification report; roll certificate must show at least the minimum und maximum values of control measurement
6.2	Visual appearance	Table 1, 1.1	Continuous	Table 1, 1.1; roll certificate must confirm satisfactory appearance
6.3	Skew and waviness	Table 1, 1.5 and 1.6	Per production start-up[2]	Table 1, 1.5 and 1.6; roll certificate must confirm in-spec skew and waviness
6.4	Weight percent carbon black[5]	Table 1, 1.3	Per production start-up and change in batch lot[3] and at least every 900 m	Requirement defined in certification report; roll certificate must give test procedure and individual values obtained
6.5	Homogeneity of carbon black distribution[5]	Table 1, 1.4	Per production start-up and change in batch lot[3] and at least every 900 m	Table 1, 1.4; roll certificate must confirm homogeneous distribution
6.6	Yield strength, Elongation at yield, Elongation at break	Table 2, 2.2; Crosshead speed: 50 mm/min up to 20% elongation, thereafter 200 mm/min / One test specimen each in extrusion and transverse directions from the edge and the middle of smooth geomembranes or from the land area of textured geomembranes[4]	Per production start-up and at least every 300 m	Requirement defined in certification report; roll certificate must show the minimum und maximum values determined in extrusion and transverse directions

[1]) In production lines without continuous automatic thickness monitoring, thickness must be measured over the entire production width every 10 m using an ultrasonic gauge.
[2]) Definition of production start-up: restart 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 certification report will specify the sampling procedure for test specimens from textured areas and the criteria to be used in their evaluation.
[5]) Only required when carbon black (batch) is added by the geomembrane manufacturer.

Table 6, Part 2: Test Procedures and Frequencies for In-House Quality Control of Geomembranes by Manufacturer

	Test Attributes	Tests / Test Specimens	Frequency	Requirements and Tolerances
6.7	Melt index and change in melt index	Table 1, 1.8 / samples from the geomembrane and the texturing material	Per production start-up and at least every 900 m	Requirement defined in certification report; roll certificate must show the MFR determined in 5.2 of Table 5 and difference to MFR of the resin
6.8	Dimensional stability	Table 1, 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)	Per production start-up and at least every 900 m	Table 1, 1.9; roll certificate must show the individual values determined and their respective sampling points
6.9	Area weight of texturing for applied texturing	In-house procedure	Per production start-up and at least every 300 m	Requirement set defined in certification report; roll certificate must show the minimum und maximum values determined
6.10	Texturing adhesion for applied texturing	In-house procedure	Per production start-up and at least every 300 m	Requirement defined in certification report; roll certificate must confirm satisfactory adhesion

Table 7: Test Procedures and Frequencies for Third-Party Inspection of Resin, Carbon Black Batch and Geomembranes

	Test Attributes	**Tests / Test Specimens**	**Requirements and Tolerances[1]**
7.1	Density	Table 5, 5.1	Set in certification report
7.2	Melt index MFR 190/5 or MFR 190/21.6	Table 5, 5.1	Set in certification report
7.3	Change in melt index	Table 6, 6.7	Set in certification report
7.4	Thickness	Table 6, 6.1	Set in certification report
7.5	Visual appearance of surface and cross-section	Table 1, 1.1 and 1.2	Table 1, 1.1 and 1.2
7.6	Visual appearance of identification markings	Visual inspection	Section 2.5 and set in certification report
7.7	Weight percent carbon black	Table 1, 1.3 / geomembrane	Set in certification report
7.8	Homogeneity of carbon black distribution	Table 1, 1.4 / geomembrane	Table 1,1.4
7.9	Dimensional stability	Table 6, 6.8	Table 1, 1.9 and Table 4, 4.2
7.10	Multiaxial bulge elongation	Table 2, 2.1	Table 2, 2.1
7.11	Yield strength Elongation at yield Elongation at break	Table 6, 6.6	Set in certification report
7.12	Static puncture resistance	Table 2, 2.4	Table 2, 2.4
7.13	Area weight of texturing (applied texturing only)	Table 6, 6.9	Table 6, 6.9
7.14	Adhesion of texturing (applied texturing only)	Table 4, 4.5 and Table 6, 6.10	Table 4, 4.5 and Table 6, 6.10
7.15	Oxidation induction time (OIT)	Based on DIN EN ISO 728, see Supplementary Instructions	Table 1, 1.11; statistically significant correlation[2] with specification for resin
7.16	Type and content of tracer	Set on case-by-case basis, test carried out by BAM / geomembrane	Confidential, disclosed to BAM

[1]) In general, the requirements specified in the requirement tables must be fulfilled. Additional requirements and tolerances characterizing the particular properties of the specific geomembrane certified are given in Appendix 1 of the certification document.

[2]) The pamphlet entitled “Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners“ is available from Laboratory IV.32, Landfill Engineering, BAM/Berlin.

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9. Standards, Guidelines, Official Gazettes und Recommendations

DIN EN ISO 60 (draft)	1999-01	Plastics – Determination of apparent density of material that can be poured from a specified funnel
DIN ISO 175	1989-04	Plastics – Methods of test for the determination of the effects of immersion in liquid chemicals
DIN EN 495-1 (draft)	1991-12	Thermoplastic and elastomeric roofing and sealing sheets; Determination of high temperature dimensional stability
DIN EN ISO 527-1	1996-04	Plastics – Determination of tensile properties - Part 1: General principles
DIN EN ISO 527-3	1995-10	Plastics – Determination of tensile properties - Part 3: Test conditions for films and sheets
DIN EN 728	1997-03	Plastics piping and ducting systems - Polyolefin pipes and fittings – Determination of oxidation induction time
DIN EN ISO 846	1997-10	Plastics – Evaluation of the action of microorganisms
DIN ISO 1133	1993-02	Plastics – Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics
DIN EN 1876-1	1998-01	Rubber or plastics coated fabrics - Low temperatures tests - Part 1: Bending test
DIN 4062	1978-09	Cold processable plastic jointing materials for sewer drains; jointing materials for prefabricated parts of concrete; requirements, testing and processing
DIN EN ISO 9000	2000	Quality management systems - Fundamentals and vocabulary
DIN EN ISO 9001	1994-08	Quality systems - Model for quality assurance in design, development, production, installation and servicing
DIN EN ISO 9002	1994-08	Quality systems -- Model for quality assurance in production, installation and servicing
DIN EN ISO 9003	1994-08	Quality systems - Model for quality assurance in final inspection and test
DIN EN ISO 9004-1	1994-08	Quality management and quality system elements -- Part 1: Guidelines
DIN EN 10204	1995-08	Metallic products - Types of inspection documents (includes Amendment A1:1995
DIN EN ISO 11358	1997-11	Plastics – Thermogravimetry (TG) of polymers -- General principles
DIN EN 12099	1997-08	Plastics piping systems - Polyethylene piping materials and components - Determination of volatile content
DIN EN ISO 12236	1996-04	Geotextiles and geotextile-related products -- Static puncture test (CBR test)
DIN 16726	1986-12	Plastic roofing sheets and plastic sheets for waterproofing; testing
DIN 16776-1	1984-12	Plastic moulding materials; polyethylene and ethylene copolymers
DIN 16887	1990-07	Determination of the long-term hydrostatic pressure resistance of thermoplastics pipes
DIN 18200	1986-12	Control (Quality control) of construction materials, construction components and construction designs; general principles
DIN 18200 (draft)	1998-12	Assessment of conformity for construction products - Certification of construction products by certification body
DIN EN ISO 17025	1999-05	General requirements for the competence of testing and calibration laboratories
DIN 53370	1976-02	Testing of plastic films; determination of the thickness by mechanical feeling
DIN 53377	1969-05	Testing of Plastic Films; Determination of Dimensional Stability
DIN 53356	1982-08	Testing of artificial leather and similar sheet materials; tear growth test
DIN 53441	1984-01	Testing of plastics; stress relaxation test
DIN 53479	1976-07	Testing of Plastics and Elastomers; Determination of Density

Standards, Guidelines, Official Gazettes und Recommendations (Continued)

DIN 53532	1989-06	Testing of elastomers; Determination of permeability of elastomer-sheetings to liquids
DIN 53861-1	1992-11	Testing of textiles; vaulting test and bursting test, tabels for the evaluation of tests
DIN 55350-11	1995-08	Concepts in quality and statistics; basic concepts in quality management, quality control and quality assurance
ISO DIS 9080		Thermoplastic pipes for the transport of fluids – Methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic strength of thermoplastics pipe materials
ASTM D1603-94	1994	Standard Test Method for Carbon Black In Olefin Plastics
ASTM D3895-97		Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
ASTM D5397-95	1995	Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
ASTM D5617-94	1994	Standard Test Method for Multi-Axial Tension Test of Geosynthetics
ASTM D5596-94	1994	Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
ASTM D5994-96	1996	Standard Test Method for Measuring Core Thickness of Textured Geomembrane
DVS R 2203-4	7/1997	Testing of Welded Joints of Thermoplastics Plates and Tubes - Tensible Creep Test
DVS M 2211	11/1979	Welding Extrudates for Thermoplastics; Area of Validity, Nomenclature, Requirements, Testing
DVS R 2225-4	7/1997	Joining of Lining Membranes Made of Polyethylene in lining of landfill and contaminated sites
DVS R 2226-1 preliminary version	8/1998	Testing of Fused Joints on Liners Made of Polymer Materials - Testing Procedure, Requirements
DVS R 2226-2	7/1997	Testing of Fused Joints on Liners Made of Polymer Materials - Lab Shear Test
DVS R 2226-3	7/1997	Test of Fusion on PE Liners – Peeling Test
GDA E 2-7	1998	Shear Resistance of Lining Systems
GDA E 2-21	1997	Calculation of Spreading Stability and Estimated Deformation on Landfill Bases
GDA E 3-8	1997	Frictional Behaviour of Geosynthetics
GDA E 7-1	1997	Static Stability Calculations of Geosynthetic Reinforcing Components in Landfills
Supplemental Information on Tests	1999	Supplemental Information on Tests for Certification of Plastic Geomembranes for Landfill Liners, Laboratory IV.32, Landfill Engineering, BAM/Berlin.
FLL Guidelines for Landscaped Roofs	1995	Guidelines for planning, construction and maintenance of landscaped roofs
R 14.3.1 TW	1998-01	PE 80 and PE 100 Pressure Pipe for Drinking Water Applications, Gütegemeinschaft Kunststoffrohre e.V., Bonn

10. Appendices to Certification Report, Numerical Codes for Federal States and Test Institutes

Appendices to Certification Report

Appendix 1: Requirements and tolerances for in-house QC and third-party inspection
Appendix 2: Designation of manufacturer with production plants and installation contractors
Appendix 3: Description of manufacturing process
Appendix 4: Materials declaration of manufacturer (type of resin, percent carbon black, use of recycle material)
Appendix 5: Description of identification markings and their configuration
Appendix 6: Description of positions of identification markings on geomembranes
Appendix 7: Description of quality assurance measures
a) in-house quality control
b) third-party inspection
Appendix 8: Manufacturer's storage and transport instructions
Appendix 9: Description of roll identification labels
Appendix 10: Description of texturing type(s) of geomembranes

Numerical Codes for Federal States

(In accordance with Federal Worksheet 4/91, page 61):

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

Institutes for Suitability Testing and Third-Party Inspection of Manufacturing:

Süddeutsches Kunststoff-Zentrum,
Officially Approved Plastics Testing Institute
Herr Glück
Frankfurter Straße 15-17 Tel: 0931 4104-0, Fax: 0931 4104-177,
D-97082 Würzburg e-mail: pf@skz.de

State Materials Testing Institute of Darmstadt,
Plastics Department
Herr Heimer
Grafenstr.2 Tel: 06151 16-2042, Fax: 06151 16-5658,
D-64283 Darmstadt e-mail: heimer@mpa-ifw.tu-darmstadt.de