Federal Institute for Materials Research and Testing (BAM)

Guidelines for the Certification of Geomembranes as a Component of Composite Liners for Municipal and Hazardous Waste Landfills and for Lining Contaminated Land

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Attention!
These guidelines are the English translation of the German certification guidelines from 1992. The German guidelines were updated recently (1999). There were changes concerning especially some of the testing procedures (e.g. the pin impression test was substituted by the notched constant tensile load test), additional requirements (e.g. OIT-testing) and all the test standards were updated. Some of the test standards had been withdrawn by the standard organisation or substituted by revised versions. So far an English translation of the new guidelines is not available. However, this version might still give you an overview about the certification approach and the main requirements concerning materials properties and quality control. Fore present-day information mail to werner.mueller@bam.de

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1. Introduction

In landfill engineering, as in other areas of the waste industry, significant developments and changes have taken place over the course of the last few years. Stimulated by ideas for a multi-barrier concept [1], there has been intensive scientific research on the characteristics and interaction of the barriers (landfill site, landfill liner, waste body, landfill use and aftercare), leading to various technical developments in the field of barrier landfill liners [2,3]. The purpose of these is to ensure reliable protection against environmentally harmful emissions from landfills and in particular the long-term protection of groundwater. The First Administrative Provision to the Waste Avoidance and Waste Management Act encourages that, in adopting the EC guidelines for groundwater protection in the field of waste management all technologically feasible precautions be taken to prevent pollution of groundwater [4]. With the issuing of the Second General Administrative Provision to the Waste Avoidance and Waste Management Act, Technical Instructions Hazardous Waste, Part 1 (TI Hazardous Waste), the state of the existing technology for the storage of wastes requiring special supervision was summarized and prescribed as guidelines for the planning, construction, use and aftercare of landfills [5]. Some States' guidelines on the storage of municipal waste already achieve this in the field of municipal waste landfills [6]. National standards, standard values and overall conditions have also been set up within the Third General Administrative Provision to the Waste Avoidance and Waste Management Act, Technical Instructions on Recycling, Treatment and Storage of Municipal Waste (TI Municipal Waste) [7]. It is hoped that as regards landfills there will be standardisation throughout Germany with respect to groundwater protection in the sense of minimum safety standards. In the remediation and containment of contaminated land, sealing problems are arising which will also be resolved on the basis of the administrative provisions issued pursuant to the Waste Avoidance and Waste Management Act. In this area the standard achieved in landfill engineering establishes the state-of-the-art techniques for lining contaminated sites.

On the basis of these regulatory instruments, the so-called composite liner is purported to be the best and the most studied liner system for forming technical barriers given the current state of technology [2, 8, 9]. The composite liner consists of a plastic liner element made of geomembrane at least 2.5mm thick, in complete surface contact with a strong, multi-lift mineral layer. A protective layer on top of the geomembrane protects it from damage by the drainage or reclamation layers. The effectiveness of this barrier with respect to pollutant transport arises from the fact that not only is convective pollutant transport prevented by the capillary-free polymer layer, but also that a pollutant concentration leap occurs at the interface due to the sequence of the non-polar (geomembrane) and polar (mineral) layers which inhibits the diffusive transport of substances [9]. The combination of the two liner elements in complete surface contact also creates a margin of safety with respect to local failure of individual components and ensures reciprocal protection.

In order to be able to fulfill its function in the long term and well beyond the operational lifetime of the landfill, the geomembrane must be especially suited to its purpose. The Lower Saxony Directive on the lining of landfills for municipal wastes [10], the TI Hazardous Waste and the drafts of other state guidelines therefore require proven suitability by means of the certification of geomembrane liner elements. The function of geomembranes within the overall landfill liner system necessitates that the certification process be not reduced merely to the certification of the individual geomembrane components as industrial products but that it ensure that these components are functionally incorporated into the overall system. In addition to the requirements for the material and the manufacture of the geomembranes deriving from the complex demands made on a landfill, specifications and conditions must be laid down so that quality control guarantees expert installation, proper welding, complete flatness over the entire surface and the expert application of suitable protective layers. The quality assurance measures for this must form part of a quality plan for the construction of the landfill liner system, as described in the TI Hazardous Waste.

Starting from the concept of the geomembrane as forming part of the complete liner system, in 1988 the Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung, BAM), under commission from the Lower Saxony Ministry of the Environment, developed a certification concept on the basis of the Lower Saxony Directive [10], at first in Laboratory 3.12, Physics and Technology of Plastics, and then in the Laboratory IV.32, Landfill Engineering. The concept is based on extensive projects and discussions related to landfill engineering carried out with the involvement of various institutions and following the Nordrhein-Westfalia guidelines on landfill basal liners made of geomembranes (NRW guidelines) [11] in connection with the Lower Saxony Directive and the Technical Instruction on Hazardous Waste in full consideration of the requirements of the TI Hazardous Waste. Thus, in addition to Lower Saxony, the certification process has been widely disseminated to other German states and has gained significance through its technical content as a certification based on the TI Hazardous Waste. This allows an applicant to employ geomembranes which have previously been certificated at great expense for other States' municipal and hazardous waste landfills with identical geomembrane requirements.

These guidelines set out the requirements, specifications and conditions of BAM certification and explain current certification practice and experience. Effort has been made to attain an extensive degree of standardization with other draft standards, guidelines and instructions while maintaining those quality standards already achieved. Proven requirements on materials have been borrowed, for example from the NRW Guidelines. Several problems in testing technology have still not been cleared up, for example the determination through testing of the long-term durability of weld seams. Current testing requirements within the certification framework for protective layers for the geomembranes are only minimal. In the future a separate certification procedure will ensure the suitability of the materials employed.

Given the dynamic development of landfill engineering, new questions and changes for the certification process are continually arising. Certain resins of carbon-black-stabilized polyethylene manufactured by low-pressure processes in accordance with the current state of knowledge and technology have been proved to be the best capillary-free polymer materials for geomembranes (resins meeting the requirements of DIN 16776-PE, EACL, 35-40, T 006-022). However, new, more flexible polyethylenes are being pushed onto the market. In addition, new manufacturing processes such as the coextrusion of multilayer geomembranes should be coming into use in the near future. The use of such flexible materials and of recycled material are suggested for landfill cappings in particular in the light of the lower chemical exposure this entails. However the requirement to use recycled material, though desirable in terms of the utilization requirements of waste management, may not meet with the requirements for defined and calculable material behaviour necessary in terms of safety. Such questions are now being extensively discussed in connection with modified certification requirements. Accordingly, the consequences arising as regards landfill cappings cannot be taken into consideration in this version of the guidelines. The BAM certification requirements are not therefore "definitive" but must be adapted to match scientific and technological advances. These necessary adaptations will be carried out in consultation with the Expert Committee which advises BAM in its certification work, a working committee under the chairmanship of a representative of the Federal Environmental Agency and composed of representatives of raw material manufacturers, geomembrane manufacturers, geomembrane installers, consultant engineering bureaux and testing institutions engaged in design and third-party control, state authorities and BAM. In addition, there is close cooperation with the German Institute for Construction Technology's (Deutsches Institut für Bautechnik, DIBT) working groups on the evaluation of landfill lining systems, who are engaged in developing the principles for the evaluation of equivalency of new landfill liner systems to the composite liner established in the

TI Hazardous Waste [12]. In this way new solutions in the field of landfill lining techniques which are economically attractive and effective in terms of safety can be put into practice as quickly as possible.

2. Legal Basis and Scope of Validity

The legal framework for measures in the field of waste management is provided by the Waste Avoidance and Waste Management Act of 27 August 1986. In implementing the Waste Avoidance and Waste Management Act and the Water Conservation Act (Wasserhaushaltsgesetz) on the protection of ground water, the Lower Saxony Ministry of the Environment, in its directive of 6-24-88 "Landfill Liners for Municipal Wastes" [10], prescribes a composite liner consisting of a mineral layer with a geomembrane resting directly on top of it as the standard liner based on the present state of the technology for the basal liner of municipal waste landfills. Proof of suitability of the geomembranes used is required. This proof must be given through a BAM certificate.

The test methods and testing requirements for geomembrane materials and requirements and conditions for the manufacture and installation of the geomembranes, required by BAM on the basis of this directive, also take into consideration the requirements for geomembranes as set down in the NRW guidelines on landfill basal liners made of geomembranes [11].

On the basis of § 4, para 5 of the Waste Avoidance and Waste Management Act, the federal government has made mandatory the prevention of ground-water pollution through state-of-the-art precautions in the storage and deposit of wastes by issuing the First General Administrative Regulation on the Requirement for the Protection of Ground Water in the Storage and Deposit of Wastes [4]. The consequences of previous pollution are to be confined and eliminated to the greatest possible extent within the current state of the technology. The technical standards and regulations, overall conditions and characteristic values for landfills for wastes suitable for landfilling have been prescribed with the issuing of the Second General Administrative Provision to the Waste Avoidance and Waste Management Act, Part 1: Technical Instructions on the Storage, Chemical, Physical and Biological Treatment, Incineration and Deposition of Waste Requiring Particular Supervision (TI Hazardous Waste) [5]. Here, too, a composite liner is foreseen as the state-of-the-art liner. No. 9.4.1 and Appendix E of the TI Hazardous Waste set down extensive requirements for materials suitability, quality assurance, quality control and third-party control of the manufacture and installation of geomembranes. These requirements are taken into consideration in BAM certification [13].

The TI Municipal Waste makes extensive reference to the requirements of the TI Hazardous Waste for landfills Class II. According to 10.4.1.1, para 4, the certification of materials for landfill lining, eg geomembranes, geotextiles etc can be carried out by BAM.

PART 1: REQUIREMENTS, SPECIFICATIONS AND CONDITIONS

3. Object for Certification

The object for certification is a geomembrane liner element as a component of a composite liner as landfill basal liners and landfill cappings for municipal waste and waste requiring special supervision and for use in lining measures in connection with the containment and remediation of contaminated land. When geomembranes are installed in landfill liners or caps generally through the use of hot-wedge welding techniques, air channels are created by utilising a double seam. Other suitable processes can be certified on application.

Geomembranes as an industrial product with defined and reproducible properties are unambiguously characterized by the following specifications:

3.1 Material for Geomembranes

The geomembrane manufacturer must provide a legally binding statement as to the resins used in the manufacture of the geomembranes and the proportion of regrind used. The permitted proportion of regrind in current production will be specified on a case-by-case basis in the certification. However it may not exceed 5%. The use of recycled material or other additives in the resin is not permitted. The geomembrane manufacturer must submit to BAM a materials specification sheet from the raw material producer for the material (resin) used in the geomembranes. This sheet must contain data on the type of resin (in the case of HDPE, in accordance with DIN 16776, Part 1), the distribution of molecular mass and at least those characteristic values listed in Table 5 as properties of the material. The data on the specification sheet are checked by BAM. In special cases it is possible that further data on the material, such as information on additives and stabilizers in the resin etc, will have to be submitted and evaluated.

3.2 Dimensions of Geomembranes

The maximum geomembrane length on a roll, the width and thickness are to be given. The requirements for nominal thickness, minimum thickness, mean values and individual values are given in Table 1. It is generally true that, regardless of its surface appearance, the minimum thickness of a geomembrane installed in a landfill liner system must be 2.50mm. The width of the geomembrane must be at least 5m. However, for a transitional period geomembranes with a 10% less width on manufacturing grounds may be certified in individual cases.

3.3 Surface Appearance of the Geomembrane

The geomembrane can be smooth on both sides or textured on one or both sides. Surface textures are to be produced in such a way that the geomembrane is not significantly weakened by notches or sudden changes in thickness in order to ensure that its long-term integrity under combined mechanical and chemical attack is not considerably reduced. This must be proved by the applicant within the framework of the certification process.

One element of the surface must be a clearly visible and highly durable identification mark at suitably frequent intervals (about every 2m^2). The mark must contain the following information, which may be coded:

XX/BAM8.3/YY/ZZ/manufacturer's logo/thickness/width/material/surface/week of manufacture/year of manufacture

In the certification code, XX indicates the states code (see Appendix D), YY the certification number and ZZ the year of certification.

To avoid the need for special cleaning of the geomembrane surface before welding, the geomembrane edges should be covered with a PE protective film which can be removed without leaving a residue.

3.4 Manufacturing Site and Process

The place of manufacture and the manufacturing process, described in detail by the manufacturer, will be established as part of the certification. If the applicant so desires, special data on the manufacturing process and all data on the raw material will be treated and retained in confidence by BAM. Before issuing the certification BAM will satisfy itself by means of a visit to the manufacturer at the place of manufacture as to the correctness of the data provided on the manufacturing process and machines as well as to the fact that suitably qualified personnel, adequate space, testing facilities and special production and testing laboratory equipment ensure satisfactory production and quality control of the manufacturing.

4. Applicants and Certificate Holders

Only the geomembrane manufacturer shall be the applicant and certificate holder. To the extent that the geomembrane manufacturer does not install the geomembranes using its own qualified personnel, it is required to nominate the geomembrane installer which will then be specified in the certificate provided it has proved to BAM that it is qualified to perform satisfactory installation and welding of the geomembranes as a component of a composite liner (see Section 7).

Within the meaning of the certification the geomembrane liner is only deemed to be built when the geomembranes are installed by the manufacturer itself or by a geomembrane installer specified in the certificate.

5. Test Methods and Requirements on Geomembranes

Tests will be carried out by BAM in Laboratory IV.32 Landfill Engineering and in testing institutes recognized by BAM (see Appendix D). BAM assumes that the applicant will be supported by the raw-material producer concerned. The acceptable ranges for results of tests carried out during quality control and third-party control will also be laid down in the certificate.

It has proved useful to classify the requirements in the following way. The characteristic values cited in the tables of requirements as a rule refer to HDPE geomembranes.

5.1 General Physical Requirements

The properties, characteristic values and test methods that characterize the general appearance of the geomembranes are listed in Table 1 (general physical requirements). The following reference properties will be determined and tested: general appearance (surface appearance, homogeneity of the material, carbon black content and homogeneity of distribution, straightness and flatness of the geomembrane), thickness of the geomembrane (individual values and mean value), density of the material, changes in melt index and viscosity number during processing, behaviour during oven ageing, behaviour during weathering and permeation rate of hydrocarbons.

5.2 Special Physical and Mechanical Requirements

Table 2 (special physical and mechanical requirements) lists the properties, characteristic values and test methods that characterize the mechanical load-bearing capacity of the geomembrane. The following properties will be tested: performance under uniaxial and multiaxial tensile load, tear propagation resistance, resistance to punctiform static loads, resistance to punctiform dynamic loads (perforation test), performance at low temperatures (folding in the cold), relaxation behaviour and seam quality.

5.3 Requirements with respect to Combined Physical and Chemical Attack

Table 3 (requirements with respect to combined physical and chemical attack) lists the properties, characteristic values and test methods that characterize the requirements with respect to physical and chemical attack. The following properties will be tested: stress crack resistance of the material and weld seam and creep strength of the material and weld seam with respect to time. For geomembranes with textured surfaces, the reduction factors will be determined by a tensile creep test in a solution of wetting agent.

5.4 Chemical and Biological Requirements

Table 4 (chemical and biological requirements) lists the properties, characteristic values and test methods that characterize requirements with respect to chemical and biological attack. The chemical resistance and resistance against microorganisms and higher plant and animal organisms will be tested.

5.5 Requirements on Resins

Table 5 shows the characteristic values for the resin set out within the certification framework. They are the density of the pigmented material, melt index, carbon black content and distribution, OIT value and viscosity number. The raw material producer must guarantee that these characteristic values are being observed within the set tolerances by means of a factory certificate issued in accordance with DIN 50049, Section 2.2. In certificating geomembranes of new types of resins, proof of several years of testing in other uses (eg liners for impoundments, liners in foundations or hydraulic engineering) should be presented for evaluation in addition to fulfilling the requirements described above.

6. Quality Control and Third-Party Control in the Manufacture of the Geomembranes

In the production of the geomembranes controlling the delivery of raw materials and regular quality control and third-party control measures guarantee uniform quality. By carrying out these measures in accordance with DIN ISO 9003, the inclusion of geomembrane manufacture in a quality assurance system such as that described in the DIN standard series DIN ISO 9000 to DIN ISO 9004 should be ensured.

In testing deliveries of resins, processing-relevant data such as melt index, density, carbon black content and distribution (see Table 5) and moisture content must be determined and recorded for random samples for each delivery. An explanation by the geomembrane manufacturer of the planned control of raw-material deliveries and of the content and method of quality control in accordance with DIN 18200 is included as an enclosure to the certificate. The properties given in Table 6 must be included within the framework of the quality control of current production and controlled in accordance with the described procedure and at the given frequency. In the tests carried out in the course of quality control, as well as in the third-party control described below, the characteristic values set out in the certificate must be attained within the tolerances given therein. The data must be archived for 20 years in such a way that the location of the test results for any one delivery unit is possible at any time. The data are to be made available to BAM on request. In order to be able to identify the delivery unit (ie the roll), it must be inscribed with an imprint (production number) in a clearly visible place prior to delivery in accordance with a model determined within the framework of the certification.

The current production of the geomembranes will be monitored at the manufacturer's expense by a neutral institution approved by BAM. The institutions charged with third-party control must have adequately qualified personnel and the requisite testing facilities must satisfy European standard DIN EN 45001 (general criteria for the operation of testing laboratories) and be recognized by the certification authority as a third-party inspector (see Appendix D). As a rule, recognition requires accreditation for the DIN tests employed in third-party control and participation in the German testing accreditation system. The control contract between the third-party inspector and the geomembrane manufacturer must be presented before certification is granted. Control includes inspection of the geomembranes, their manufacture and quality control. DIN 18200 and the other requirements set out in the control contract between the third-party inspector and the geomembrane manufacturer are crucial to the control.

With respect to testing of the geomembranes, all of the tests to be carried out within the framework of quality control (see Table 6) are also to be performed within the framework of third-party control (see Table 7). In addition, the tests for the following properties from Tables 1 and 2 are to be performed: density, behaviour under uniaxial and multiaxial tensile loading (uniaxial loading at 70°C), tear propagation resistance, puncture resistance (perforation test), resistance to quasi-static single loads (punch penetration test) and behaviour at low temperatures (folding in the cold). The nature and extent of quality control is to be checked by factory visits through inspection tours and document review.

At the start of production, the third-party inspector must be satisfied that the preconditions for proper production and quality control are present. Third-party control measures must be carried out twice a year. If a manufacturer produces both certified double-side smooth geomembranes and certified textured geomembranes, control must be carried out twice a year for each of the product groups "smooth geomembranes" and "textured geomembranes". Production samples must be taken by the third-party inspector. As a rule, control visits are to be carried out without advance warning. In this connection, third-party control must take place in the manufacture of those geomembranes that are marked in accordance with BAM certification and are used as certified geomembranes. Since not only BAM-certified geomembranes are produced all the time, the third-party inspector must orientate the planning of control measures to the manufacturer's production plans, about which the third-party inspector must be informed in a timely and complete way. Proof of third-party control performed is provided by the third-party inspector forwarding the control reports to the certification authority (BAM) regularly and without their being requested. This must be agreed to in the control contract. In the case of defects, procedures determined by the third-party inspector are to be followed. In the case of repeated or serious defects, the certification authority is to be informed.

7. Requirements on Geomembrane Installers and for Geomembrane Installation by the Geomembrane Manufacturers

To the extent the geomembrane manufacturer does not install the geomembranes and provide the proof described below itself, geomembrane installers shall be listed on the certificate at the manufacturer's request. This must be a geomembrane installer experienced and qualified in the installation and seaming of geomembranes. Experience and qualifications must first be proved by furnishing a reference list of the installation measures carried out in the past (place of installation, clients, technical authorities, certification authorities and third-party inspectors), second by evidence and proof, not more than two years old, of the qualifications (see Section 8.5) of the geomembrane intallers and welders employed, and finally by documentation of the training measures that the geomembrane manufacturer has provided to the geomembrane installer in the use of its geomembranes.

The important points of the geomembrane installation guidelines on the basis of which the geomembrane installer works form an enclosure to the certificate. In addition, the quality assurance measure within the framework of quality control and their incorporation into the quality system of the geomembrane installer must be described. In this connection, the nature and scope of the tests and the method of recording and archiving of the data are to be provided. The training and expertise of the testing personnel and their areas of competence and decision-making authority are to be described. In this connection, the specifications and conditions in the certificate described in Section 8, in particular 8.4 (installation of geomembranes) and 8.5 (welding of geomembranes and construction site tests), and the requirements given in Section 9 are to be observed. Within the framework of the procedure for including the geomembrane installer in the certificate, the certification authority will carry out a visit to the landfill where the installation is taking place in order to gain a first-hand impression of the quality and expertise with which the geomembrane installation work is being carried out. In this connection, the data from the manufacturer and the geomembrane installer regarding the geomembrane installation work will be verified. A visit to the installation site will frequently only be possible after the certification is granted. In this event, the certification will contain the condition that this visit will be facilitated at the earliest possible opportunity.

In order to have the skilled workmanship assessed, samples of weld seams will be produced by qualified personnel from the geomembrane installer either at BAM or at the geomembrane installer's premises in the presence of a BAM representative. The sample weld seams will be tested at BAM or at a testing institute recognized by BAM. Double seams with air channels and double-seam T-joints will be produced with welding machines and fillet seams and fillet seam T-joints will be hand welded using extrusion weld equipment. In addition, samples of geomembrane edges covered with a protective film and samples of pre-treated surfaces will be tested in the condition they are in immediately before being welded together. The equipment and tools used for the surface treatment of uncovered geomembrane edges will be determined in the course of certification and will be described in an enclosure to the certificate.

In testing the seams, first the external appearance and dimensions will be evaluated and the strength of the seams will then be tested in the tensile test and peeling test described in Table 2, point 14. To test watertightness and strength, a water-pressure test analogous to the compressed-air test in DVS guideline 2225, Part 2, will be carried out. The duration of the test will be 10 minutes. The basis of evaluation will be that pressures in excess of 20bars can be held in the air channel of good-quality weld seams. Out-of-plane tests will be performed on the samples (see Table 2, point 8.1). Samples with a good-quality double seam or fillet seam will attain bubble heights close to those of the unwelded basic material. Samples with T-joints should attain a standard value for arch elongation of at least 6%. The quality of the surface treatment before welding will be evaluated (see Section 8.5). When protective films are used in the vicinity of the seam, the films will be tested as to whether they adhere well and can be removed without aving a residue.

8. Specifications and Conditions for the Installation of Geomembranes as Part of a Composite Liner

The following specifications and conditions must be met in the installation of geomembranes as a component of a composite liner. The purpose of this is so that the geomembrane resting on top of the mineral layer is so constructed that the application of future overburden such as protective layers, drainage layers, waste layers and reclamation layers will bring about full surface contact (hereinafter referred to as an intimate contact) between the geomembrane and the mineral layer. Compliance with the specifications and conditions is to be ensured by the quality control measures of the geomembrane installer or the geomembrane manufacturer, by third-party inspector under agreement with the responsible technical authority (eg an outside engineering bureau or institute), and finally through control by the technical authority (see Section 9). However, the specifications and conditions must already have been taken into consideration by having experts qualified in synthetic materials participate in the planning and in drawing up the list of requirements for the invitation to tender. Prior to the invitation to tender and the awarding of the contract, the planning documents must be submitted to the third-party inspector for the installation of the geomembranes, which as a rule will already have been named by the technical authority and examined by the third-party inspector with respect to the quality system.

8.1 Transportation and Storage of the Geomembranes

The transportation of the rolls of geomembrane to the landfill construction site may only be done by companies contracted by the manufacturer. Damage to the rolls during transportation is to be reported to the manufacturer by the geomembrane installer. Handling on the construction site may only be carried out by trained personnel of the manufacturer or geomembrane installer using tested equipment that will as a rule have been approved in advance by the manufacturer. The third-party inspector for the installation of the geomembranes must satisfy himself that the rolls are undamaged before releasing them for installation. In the event of damage, procedures must be followed as the third-party inspector directs. Interim storage on the construction site must take place in a prepared storage place in such a way that both deformation which would impair the installation of the geomembranes and damage to the rolls through storage and construction operations will be avoided. A minimum of transportation should be employed in the subsequent installation of the geomembranes. If the individual rolls are not provided with transportation packaging, the rolls are to be protected from the weather by being covered with film or by means of other suitable measures. The site must be secured against unauthorized entry.

The manufacturer must detail its transportation and storage instructions in an enclosure to the certificate.

8.2 Subgrade, Base and Side Slope

The geomembrane liner is to be installed free of distortion and folds and without producing undulations that would inhibit the intimate contact. This should be facilitated by the side slope and base having "developable" geometric contours which permit the installation of rectangular geomembranes. Deformations in the subgrade must not interfere with the functioning of the landfill liner system. The subgrade and the mineral layer must be so stable that in the worst case the geomembranes will not incur more than 3% multiaxial elongation as a result of local settling. The stability of the liner system, particularly as regards areas of slope, is to be proved by stress analysis for the actual installation site. Prior to installation, it must be ensured (as a rule in a test site) that the design parametres (eg friction angle) for the stress analysis of the slope stability are met by the materials to be used. The measures to be taken for this purpose must be set out in the quality plan. In designing the side slopes care must be taken that the shear resistance within the liner system at the planned maximum waste loads increases with depth, ie the shear resistance between the surface of the mineral layer and the geomembrane is demonstrably greater than the shear resistance between the geomembrane and the protective layer. The radius of the transition zone between the side slope and the base must be >1m. The runout and anchor trenches and their corners are to be laid out and rounded in such a way that no folds are produced in the geomembranes.

8.3 Surface of the Mineral Layer

The surface of the mineral layer must be produced in such a way that no mechanical damage occurs to the geomembranes from the intimate contact. Immediately before the installation of the geomembranes the surface of the mineral layer is to be declared as satisfactory by the project manager, the installer and the third-party inspector. Declaration and eventual acceptance by the responsible technical authority of the mineral layer must be co-ordinated with minimum delay. The maximum extent of each acceptance shall be the area onto which the geomembrane can be installed and welded in one working day. Should the surface of the mineral layer not correspond to the requirements to achieve the intimate contact, under no circumstances is any geomembrane installation to take place.

The surface must be free of non-continuous or abrupt changes and have no lumps or foreign bodies lying on top of it. Steps (impression differences) 0.5cm in height may be tolerated. Surface depressions when measured beneath a straightedge (level) 4m in length may not exceed 2cm. An exception is moulds in the base to accept leachate collection trenches. Through the proper selection of materials and installation methods it must be ensured that the surface has no lumps with a diameter greater than 10mm on or in it and that all finer floating gravel components are embedded in such a way that they are surrounded on all sides by binding mineral material. An evaluation of the surface of the mineral layer must already have been made at the test site. The surface prepared for the installation of the geomembranes must be protected against drying (formation of desiccation cracks, powdery dry surface), water accumulation, flooding (waterlogged surface) and hard freezing. If this is not done, the last lift of the mineral layer must be appropriately reconditioned before the geomembrane is installed. These requirements apply analogously to the anchor trenches and to the top of the berm.

8.4 Installation of Geomembranes

The geomembranes shall be installed in accordance with an installation plan that has been approved by the responsible technical authority and the third-party inspector. As a rule, installation of geomembranes is only permitted between April and October. Exceptions may only be made in the case of very favourable weather conditions or where some form of weatherproof protection is employed and with the approval of the technical authority and the third-party inspector, provided no loss of quality in the liner system is anticipated. In general no geomembrane installation is possible when the air temperature is below 5°C, when there is any kind of precipitation or when there is standing water on the surface. This is also true when there is wind or strong solar radiation if these impair the satisfactory construction of the liner elements. When the work of installation of the first geomembranes (installation and seaming) begins, the equipment, vehicles and geomembrane installation and securing methods used will be tested. This will be done in accordance with the conditions laid down by the third-party inspector and should conform to the requirements laid down in this section and in Section 8.5 as modified by the results of site specific field testing. As a rule the operations used for installing the geomembranes shall be included in the construction of the mineral layer test site in order to co-ordinate the various engineering measures needed for constructing the liner system. Subsequent deviations from the established procedures, machinery and equipment may only take place with the prior approval of the third-party inspector.
Every geomembrane sheet that is installed has an as-built number that is listed in the geomembrane installation or as-built plan. Unequivocal identification of the as-built number, BAM mark (see Section 3.3) and manufacturer's production number must ensure it is possible to identify the geomembrane material, batch, manufacturer and date of manufacture exactly. The geomembranes are to be laid with the BAM mark facing upwards. The installation must be carried out without folds and with a minimum of undulations so that it is certain that the geomembranes have attained a planar position on the mineral layer prior to the application of the protective and drainage layers. Any and all damage affecting the watertightness and load-bearing capacity of the geomembrane must be repaired. Repairs are to be carried out with the approval of the third-party inspector. The third-party inspector can also prescribe replacement of the geomembrane if necessary. All repairs are to be logged so that the nature and position of the repair (as-built drawing), welder, weld seams and weld-seam tests are recorded. Satisfactory repair is to be confirmed by the third-party inspector in the log.

8.5 Welding of Geomembranes and Construction Site Tests

The planned welding procedure, weld-seam geometry and test method are to be described by the manufacturer in an enclosure to the certificate for the geomembrane installer named therein. The basis for the welding operations will be the requirements of DVS Guideline 2225, "Seaming of geomembranes of polymer materials in earthworks and hydraulic engineering". In addition the following conditions are to be observed. In general, on the side slopes the weld seams are to be orientated in the direction of dip. Seams in the base which run parallel to the side slope must be at a minimum distance of 1.5m from the foot of the slope. Exceptions, eg in the case of repairs, are possible only with the approval of the third-party inspector. Every seam is to be indicated in the installation plan (as-built drawing) in such a way that it can be assigned to the accompanying welding record. In the case of connection operations (expansions of landfills) only geomembranes of the same resin may be welded together. If, in an individual case, this is not possible, proof should be given to the responsible technical authority by means of an expert's certificate that the welding together of different resins will produce satisfactory seams. Where the extension of existing landfills lined with non-certified geomembranes is necessary, an expert's decision over the suitability of connection to a certified geomembrane is required on a site specific basis.

Only those welders may be employed who are trained in the technique of seaming HDPE geomembranes and who have valid test certificates issued in accordance with DVS Guideline 2212, Part 3, "Testing of plastics welders, test group III, geomembranes in earthworks and hydraulic engineering", at least subgroup III-1, III-2 and III-3, showing that they are attested plastics welders for geomembranes in earthworks and hydraulic engineering. The tests must be certified by an impartial institute that carries out training of plastics welders in accordance with the requirements of DVS Guideline 2212. Before the welders are first used on any landfill construction site the third-party inspector must satisfy himself that the welders are capable of producing satisfactory seams with the planned welding machinery and equipment, and shall have them prepare weld samples for this purpose. The third-party inspector must test the functional quality of the welding machinery and equipment planned for use.

The areas where the geomembranes are to be seamed need not be specially cleaned provided they have been covered with a PE protective film by the manufacturer and this is removed shortly before welding so that they remain clean. All other seam areas are to be cleaned of all dirt. In this connection, only those cleaning agents described in the enclosure to the certificate may be used. Moreover, the areas for fillet seams produced by extrusion welding must be mechanically freed of the oxide layer without the creation of visible grooves in the unwelded area, in accordance with the procedure described in the enclosure to the certificate. Visible grooves in the surface, particularly those parallel to the weld seam, must also be avoided when the surface structures are removed in the welding of cross-seams and T-joints.

In general seams are to be hot-wedge welded. In this connection, they are to be produced as overlapped seams with air channels (double seam) using a welding machine. The width of the seams, measured across the effective pressure width of the pressure roll, shall be at least 2 x 15mm. The interior width of the air channel must be at least 15mm. The widths must be maintained within a tolerance of ±2mm. The measurements and external appearance of the weld seams and the air channel must correspond to the data in the enclosure to the certificate. In the event that double seams cannot be produced, hand-welded fillet seams may be produced by means of extrusion welding after prior stitching. Resin for the extrusion welding must be the same resin as for the geomembrane. The effective seam width must be greater than 30mm. Welding records are to be kept, a model of the type and scope of which will have been established in the enclosure to the certificate, though these may be extended at the discretion of the third-party inspector. To the extent that the weld seams do not need to be made using hand equipment, only those welding machines shall be used which make it possible to document continuously the time, path, pressure of the pressure rolls, hot-wedge temperature and welding speed and deviations of these from the prescribed values in order that it is possible to exactly assign these parameters to each running meter of the weld seam. Moreover, it is recommended that special equipment be used to continuously record deviations from the prescribed thickness of the weld seam and various ambient parameters such as atmospheric humidity, outside temperature and the temperature of the geomembrane. Other requirements for the welding equipment and machinery are set out in DVS Guideline 2225, Part 3, "Requirements for welding machines and welding equipment", and these must be observed.

The external appearance, dimensions, strength and watertightness of the seams are to be tested within the framework of quality control in accordance with DVS Guideline 2225, Part 2, "Construction site testing". The tests made under quality control, as well as the samples taken and tests made within the framework of third-party control, must be carried out in accordance with DIN 18200 in such a way that the test results are available before the application of the protective and drainage layers so as to allow economical repair if necessary. On-site seam-strength tests (peeling tests) are to be made using transportable tensile testing machines which enable testing at a constant test speed (50mm per min).

In principle, all seams are to be tested for watertightness. The testing of the double seams with air channels shall be carried out using compressed air in accordance with the following conditions: at surface temperatures between 5 and 20°C with a test pressure of 5 bars, at temperatures between 20 and 40°C with 4 bars and at temperatures between 40 and 50°C with 3 bars. The test pressure applied is to be increased by 0.5bars over a short period of time (around 1 minute) and then reduced back to test pressure. The actual test begins after the test pressure is once again attained. The test is considered to be valid if the pressure does not fall more than 10% after a test period of 10 minutes. Single seams shall be continuously subjected to "vacuum testing" using a vacuum chamber. The permitted wetting liquids used to test the seams through bubble formation are listed in the enclosure to the certificate. In addition, seams are to be tested for homogeneity on a sample basis using ultrasonic testing. Records are to be kept of the seam tests, a model of the type and scope of which will have been established in the enclosure to the certificate, but these may be extended at the discretion of the third-party inspector.

8.6 Protective and Drainage Layers

Between the geomembrane and the drainage layer (eg 16/32mm gravel) there is to be a protective layer that protects the geomembrane from any punctiform detrimental deformations during construction and use. This protective layer is to be designed with reference to the future maximum overburden (landfill height) and the expected operating temperature at the base. In this connection, it is to be ensured that the shear resistance essential for slope stability is not altered adversely.

The geomembrane on the side slope and base surface is to be covered with a protective and a drainage layer following each stage of geomembrane installation after flatness has been achieved, generally daily, in order to prevent any build-up of condensation between the geomembrane and the upper surface of the mineral layer by applying a sufficient load. The selection of the size of the panels must be determined on the basis of the installation and the weather in field testing or at the test site and is within the discretion of the responsible technical authority and the third-party inspector. The third-party inspector must satisfy himself in field testing or at the test site that the technique used for installation and application of the protective layer will not harm the geomembrane.

8.7 Advance Test Methods and Requirements on the Protective Layer

The effectiveness and durability of the protective layer must be proved. In approving the suitability of the protective layer in accordance with the current state of knowledge the following test methods and requirements must be applied so as to satisfy the effectiveness requirements with respect to static loads and durability. Since there is no compulsory certification for protective layers, the satisfaction of these requirements is to be verified through testing certificates from neutral institutions. These certificates must be called for in the tender invitation. They are to be submitted to the third-party inspector for approval before work starts on construction of the liner system.

The suitability with regard to the mechanical protective effect is to be proved by means of a load-plate pressure test. In this connection, the test characteristic is the appearance of the geomembrane after loading. For landfill overburdens up to 650kN/m^2 or 450kN/m^2 at the higher expected operating temperatures (40°C), the testing structure described below can be used. At higher landfill overburdens, the structure (choice of test base) and testing conditions (accelerated testing through overload or elevated temperature) are to be determined on a case-by-case basis.

With the layer to be tested constructed from the bottom up ("sub-soil", geomembrane (smooth), protective layer, 16/32mm gravel drainage layer 20cm thick, sand regulating layer 5cm thick, pressure plate) at 40°C, a 1,000-hour pressure test is carried out in a pressure container at least 30cm in diameter. A 1.5 to 2cm thick elastomer plate with a shore-A hardness of 50 is used as the "subsoil", ie the test base. The test pressure P_p measured below the test base, is determined from $P_p = 1.5 \times P_{overburden}$. $P_{overburden}$ is determined from the planned maximum height of the landfill and the average specific gravity of the waste body. The factor 1.5 takes into consideration that after a test period of 1,000 hours, deformation is still not complete. The protective layer is considered suitable if immediately after the 1000-hour creep pressure test the detectable dents in the 2.5mm thick smooth geomembrane correspond to a greatest maximum elongation of 0.25% (calculated on the basis of a circular segment with the smallest extent of the dent as the length of cord and the greatest depth of the dent as the height). The elongation can be determined experimentally by placing a soft metal plate (an organ pipe plate) under the geomembrane so that the maximum deformations on the geomembrane can be ascertained by measuring the deformations on the plate. In a simplified test, the surface of the geomembrane can be assessed visually 24 hours after it is removed (conditioning at a normal climate of 23/50). In any event, a sufficient protective effect is obtained when no visible deformations are still present. Nicks, tears and perforations represent unpermissible damage that makes the protective layer unsuitable.

The protective layer has to fulfill its protective function for at least the expected life-span of the geomembrane. Until its suitability has been established in a certification process, the biological and chemical integrity of the components of a protective layer made of polymers must be proved by tests carried out in accordance with the test methods and requirements in Table 4 of these certification guidelines. In this connection, the test procedures are to be modified in ways suited to the materials. The suitability of other components of the protective layer, such as mineral substances, must also be proved.

9. Quality Assurance and Control in the Installation of the Geomembrane Liner

The installation of a landfill liner system by the responsible contractor (general contractor) must be incorporated into a quality system as described in the standard series DIN ISO 9000 to DIN ISO 9004. The measures taken to install the geomembrane element represent a component of this quality system. The quality system must facilitate co-ordinated cooperation between the geomembrane installer and all other subcontractors on the construction site. In this connection, a quality plan governs quality control and quality surveillance (for terms see DIN 55350, part 11). The requirements and conditions cited in Section 8 must be contained within the quality control and quality surveillance measures. The quality control undertaken by the geomembrane installer, as described in the geomembrane installation guidelines in the enclosure to the certificate, forms part of the quality surveillance measures. A specialist of the installer experienced in geomembrane installation and responsible for quality control must be present at all times of the geomembrane installion as a specialized project manager.

The third-party control of the installation of the geomembranes within the framework of quality control and surveillance must be carried out in accordance with DIN 18200 by a third-party inspector who is a plastics expert. As a rule he should be a specialist with at least a specialized technical college degree as an engineer with certified in-depth knowledge in the field of plastics processing and landfill engineering. This specialist must be present at all the times throughout the geomembrane installation work, ie from the acceptance of the surface of the mineral layer to the application of the drainage system. In particular, he must ensure that the geomembrane liner is constructed consistently in compliance with the data in the certificate and its enclosures and with the specifications and conditions outlined in Section 8.

With regard to surveillance within the framework of quality control and third-party control as well as the lining system's eventual acceptance, the requirements found in the Lower Saxony Directive, Section 5 (Surveillance) and Section 6 (Documentation) and the TI Hazardous Waste, Enclosure E, Part 3 (Quality Assurance and Acceptance) are also applicable.

10. Modifications, Deficiency Reports and Period of Validity

Changes in the object for certification, ie resin, dimensions and the surface appearance, including the identification of the geomembranes, manufacturing and seaming procedures in the manufacturing plant, geomembrane installation and construction procedures of the named geomembrane installer or in the purpose of use require a new certification or an amendment. The period of validity of the certification is five years and may be extended on application. If the manufacture, transportation or installation violates essential requirements and conditions of the certification the manufactured and installed geomembrane is deemed unsuitable and is not certified. Repeated or significant faults in the manufacture or installation of geomembranes and instances of damage to landfill liners related to the object of the certification are to be reported immediately to the certification authority by the testing institution responsible for third-party control of the manufacture or by the third-party inspector overseeing the installation via the responsible approving or technical authorities.

PART 2: CLARIFICATIONS

11. Object for Certification and Certificate Holder

The aim of the certification is to ensure suitable materials selection, manufacture and installation of functional geomembranes with long-term integrity as a component of a composite liner. As an essential functional feature of a composite liner, the geomembrane must be expertly installed in close surface contact with the mineral layer by a qualified geomembrane installer in such a way that consecutive loads such as the drainage, waste and reclamation layers lead to an intimate contact between the geomembrane and the mineral layer over the whole surface. The TI Hazardous Waste takes this into consideration by requiring a certificate of suitability not only for geomembranes but also for the seaming technology (TI Hazardous Waste, Appendix E, 2.2). The certification has not only to set out tests conducted in connection with the quality control and third-party control of the geomembrane manufacturer, but also tests which ensure the expert installation of the composite liner (TI Hazardous Waste, Enclosure E, 3.2.2). The object for certification is therefore the geomembrane liner element as a component of the composite liner and the requirements for the object of the certification encompass three areas. In the first place, the geomembrane as an industrial product must be suitable as the liner element of a landfill liner system with respect to selection of materials and manufacturing process. Secondly, requirements for the geomembrane seaming and installation operations of the geomembrane installer or for geomembrane installation by the manufacturer itself as well as requirements and conditions for expert installation of the geomembranes as a component of a composite liner must be established. And thirdly, quality control and third-party control measures within the framework of a quality system must ensure that all requirements for the manufacture and installation are observed.

With regard to selection of materials in particular but also to installation techniques certain materials and procedures have in recent years proved to be particularly suitable for landfill construction requirements and can therefore be considered to be state-of-the-art. Certain resins of carbon-black-stabilized polyethylene produced in a low-pressure process have gained acceptance as the capillary-free polymer material for geomembranes on the basis of present-day experience and knowledge. Other plastics are not currently considered suitable materials, at least for the basal liner (see Section 12), therefore, the data in Part 1 Sections 3 and 5 relate primarily to this material. The hot-wedge welding procedure has been generally accepted as the state-of-the-art in seaming technology. In particular, the welding machines available for this procedure make possible continuous adjustment, control and recording of the welding parameters. It must be possible to test the seams for watertightness throughout and non-destructively. They are therefore produced as overlapped seams with an air channel, by which means a thorough watertightness test is possible using air pressure. Ultrasonic testing and high-voltage electrical testing in their present state of development do not in themselves represent thorough methods suitable for the construction site. However, these data on materials and seaming technology have not been "definitively" established. Technical changes and new developments in so far as they are in the interests of technical progress or of economic progress with the same quality standards, are in principle welcome and will therefore be explicitly supported by BAM.

Geomembranes are characterized by their material, dimensions, surface appearance and manufacturing process. The various data on the material must enable unequivocal identification (fingerprinting) of the geomembrane material, for example in cases of damage. In regulatory instruments the minimum thickness of the geomembrane is established as 2.50mm. With regard to durability, integrity and the required watertightness, as well as manufacture, manageability and weldability, geomembrane thicknesses of 2.5mm to 3mm represent a good compromise. In order to minimise possible areas of failure and weak points, the number of weld seams should be reduced by using wider geomembranes.

However width is limited by manufacturing problems, the weight of the rolls and the associated transportation and on-site manageability problems. Today geomembranes 5m wide can certainly be manufactured and installed. Consequently, considerably narrower geomembranes, say widths of 1.5m or 3m, or geomembranes that achieve the minimum width by being prefabricated from narrower geomembranes are no longer certified. In order to take into consideration national variations, for a transition period (2 years) geomembranes with widths 10% less than the minimum width of 5m can be certified.

The geomembrane manufacturer is always the applicant and the certificate holder. The manufacture, delivery and installation of the geomembranes and the associated guarantees must to a large degree be the responsibility of an economically sound contractor, the manufacturer, who best knows the processing requirements for his materials and products. In addition the installation of the geomembrane in a fault-free composite liner requires high-quality preparation and the presence of engineers on the construction site as well as a suitable quality system for the geomembrane installation. This too can only be guaranteed by the geomembrane manufacturer or by a suitably equipped and experienced geomembrane installer as the manufacturer's business partner or through close co-operation between the manufacturer and the geomembrane installer. For this reason, suitable geomembrane installers are included in the certificate only at the request of the manufacturer. Thus a liner element is constructed within the meaning of the certification only if the geomembranes have been installed by the manufacturer itself or by a geomembrane installer nominated in the certificate and accepted by a responsible, qualified third-party inspector. The assignment of work to subcontractors not listed in the relevant certificate violates the certification conditions. The employer should also avoid having the geomembrane manufacturer engaged as the subcontractor of a general contractor without having insight into the details of the sub-contract with respect to quality, satisfaction of requirements and conditions of certification and guarantees of work performance (see [14]). Faulty construction performance may in many cases be traced back to failures in the invitation for tenders and the contract award.

12. Requirements on Geomembranes

BAM's more than two decades of experience with polyethylene materials has influenced the requirements (properties, quantities and test methods) placed on geomembranes within the certification framework and which follow the requirements tables of the NRW guidelines [11, 14]. In recent years these have been revised and further developed on the basis of the changing state of the technology [15]. It has been proved useful to divide the requirements into general physical requirements, special physical and mechanical requirements, requirements with respect to combined physical and chemical attack, and the chemical and biological requirements. While these requirements are only explained here in brief, more detailed remarks may be found in [2], [11] and [15] and in the further references cited therein.

The general physical properties of the geomembranes are influenced not only by their basic material but also by the way in which the material is processed. Manufacturing appropriate to the material in which differences in the melt indices of the resin and the geomembrane may only lie within prescribed narrow tolerances must produce geomembranes with a defect-free surface and homogeneity of material. These geomembranes must exhibit a pronounced straightness and flatness and have only low shrinkage when warmed in order to make possible even, low-tension welding without creating undulation. Installation conditions require that the geomembrane exhibit suitable weather resistance.

Oven ageing gives an indication of satisfactory processing and also make it possible to forecast resistance to thermal oxidative degradation. The permeation values for the "key substances" trichloroethylene and acetone indicate the permeation behaviour of harmful organic substances through the geomembranes.

The geomembranes must withstand various mechanical attacks. Additional loading over a long period of time can occur in the vicinity of the side slopes or can be caused by subsidence. In addition, short-term mechanical loads can sometimes occur during the construction phase. Therefore requirements for uniaxial and multiaxial deformation behaviour and mechanical robustness (puncture resistance, tear propagation resistance and folding behaviour) are established. Since these are very time consuming, the chemical and physical tests are the most costly. However, they are particularly important within the certification process for characterizing long-term behaviour. The most important properties to assess in the long-term performance of geomembranes under mechanical loads are as follows: stress crack resistance as shown by an accelerated stress crack test, creep strength as determined by internal pressure creep tests on pipes of the same material, relaxation behaviour and durability of the weld seams [16].

A number of factors including material properties, the surface appearance of the geomembranes (dirtiness, oxide layer, pre-treatment) as well as the parameters of the seaming technology, welding speed, welding temperature and seaming strength during hot-wedge welding and the resulting seam geometry (thickness, geometry of the melt layer and bead) determine the long-term durability, resistance and watertightness of the seam. By assessing the seam geometry and conducting a peeling test, the welding parameters are optimized on the construction site. "Good" weld seams basically exhibit clear stretching of the base material near the seam during the peeling test. The seam itself remains undamaged.

Laboratory tests and tests on seams dug up from existing landfills show that the weld seams of HDPE geomembranes have very good chemical resistance. BAM studies such as peeling tests at extremely slow drawing-off speeds after immersion and oven ageing and microanalytic studies of the appearance of the material in the area of the seaming plane should provide further information in this regard as work continues in places such as the South German Centre for Plastics [22]. At the present time, however, there are no test methods available, apart from short-term tests (Table 2, 14), which would make it possible to differentiate further between geomembranes of various HDPE resins with respect to the long-term durability of the seam strength having optimized welding parameters in terms of durability.

When weld seams are subject to long-term mechanical shear stresses the basic material fails at the edge of seams which have proved good in short-term tests, the actual area of the seam remaining intact. This is shown by tensile creep tests and relaxation tests. The weld geometry, in particular the shape and size of the bead that protrudes in the vicinity of the edge as a result of melt flow and the shape and size of the melt, has a considerable influence on this long-term durability. For this reason criteria for assessing the weld geometry have been derived and in future these must be developed further and refined [22].

The determination of long-term welding factors (reduction factors with respect to the operational life) in the tensile creep test is presented in detail in [17]. However, the dependence of long-term behaviour of the weld parameters and seam geometry in the tensile creep test or the relaxation test is still not sufficiently well understood to establish uniform standard values. More extensive research on this subject will also be undertaken in BAM.

An additional component of the requirements are tests that characterize the resistance to chemical and biological attack. Here again they are concerned with the long-term behaviour of the geomembranes in the extreme chemical and microbiological conditions found in landfills. The chemical conditions depend strongly on the type of landfill, however they frequently differ greatly even in landfills of the same type. The immersion tests are therefore carried out with "typical" media consisting of the most diverse types of substances, as set out in the NRW guidelines. Tests for resistance to roots and burrowing animals play a particularly important role in the durability of a landfill capping.

With respect to these requirements, the only geomembranes currently certified are those of carbon-black-stabilized HDPE resins in accordance with DIN 16776-PE, EACL, 35-40 T 006-022 (ie with a naturally pigmented density between 0.932 and 0.942g/cm^3, melt index values generally between 0.4 and 1.8g/10 min (190/5) and 1.8-2.6% by weight carbon-black-stabilized). These resins should be pigmented by their producers since it is difficult to achieve a satisfactory homogeneity of carbon-black distribution when the pigment is added by the geomembrane manufacturer. There are various reasons for only certifying geomembranes made of a polyethylene material. This material displays negligible permeation by harmful inorganic substances (heavy metals). In combination with the mineral layer, a high barrier effect can also be achieved for harmful organic substances [9].

HDPE is characterized by very good chemical resistance and it has been proved that microbiological degradation is not to be expected. The carbon black content and the homogeneity of the carbon black distribution guarantee the required resistance to weather. Taking into consideration the reduction factors that have to be calculated for the weld seams it is difficult to make precise forecasts of life span given the complex attacks in the landfill and the diverse damage mechanisms. Based on the present state of knowledge, however, under the deformation values, temperatures and leachate components to be expected in a landfill, this material can withstand failure due to deformation-related stress-crack formation caused by installation or subsidence and by the attack of swelling or surface-tension-reducing media well beyond the operational life of the landfill [16]. This is also true for thermal oxidative degradation (operational life of a landfill is 15-30 years; the life span of the HDPE geomembranes can be assessed as at least 50 years, though this period is presumably considerably longer [2, 16]). The premise for this is good relaxation behaviour, ie relaxation behaviour that quickly reduces stresses. HDPE geomembranes exhibit outstanding robustness and weather resistance for use at the construction site and satisfactory processing properties. Finally, an unbroken chain of quality assurance measures can be guaranteed from delivery of the material to its installation [2].

Increasingly geomembranes with textured surfaces are being used. In this way friction values necessary for adequate stability on side slopes can be achieved. However the textured surfaces must be designed (by avoiding notches and sudden changes in the thickness of the material) in such a way that the long-term behaviour of the geomembrane will not be significantly weakened in the face of combined mechanical and chemical attack. For this purpose reduction factors are determined by tensile creep tests based on the example of the tests conducted to determine the long-term durability of weld seams [17]. In so far as the overall stability of the landfill construction requires special measures, textured geomembranes may also be installed on the base.

13. Quality Control and Third-Party Control

Quality control and third-party control ensure that the characteristics of the manufactured geomembranes correspond to those of the test models in the certification procedure. The characteristic values determined in the tests conducted through quality control and third-party control must therefore agree within the given tolerances with the standard values determined in the certification process and set out in the enclosures to the certificate. The third-party control tests for BAM-certified geomem-

branes include as a subset the tests contemplated for third-party control in the NRW guidelines as well as third-party control tests within the certification framework of the German Institute for Construction Technology (Deutsches Institut für Bautechnik, DIBT) in accordance with construction and testing principles for geomembranes as lining elements of collecting troughs and rooms for the storage of water-polluting liquids. Therefore, in an arrangement between the manufacturer and the controlling institution, tests carried out and results determined as part of the biannual third-party control measures may also be used as third-party control measures for DIBT-certification, NRW third-party control and for BAM-certification.

14. Installation of Geomembranes as Part of a Composite Liner

The installation of the geomembranes in a composite liner requires that a large number of engineering requirements be satisfied. Since installation defects are the essential cause of failures in the geomembrane elements, special requirements and conditions for installation are set out in the certificate. These form the basis for the work of the geomembrane installer and the third-party inspector but the institutions engaged in planning and preparing tenders, the on-site project manager and the approving and technical authorities must also be familiar with these specifications and conditions and make them part of their working documentation. Thus, the specifications and conditions for the installation of geomembranes in the composite liner comprise, supplement and give specific form to the requirements set out in the Lower Saxony Directive, Appendix 2, "Landfill Liners for Municipal Wastes: Requirements for Material, Installation Technology and Testing", and in the TI Hazardous Waste, Appendix E, Section 3, "Quality Assurance and Acceptance". For the requirements for seaming technology and construction-site testing, reference is extensively made to the relevant guidelines of the German Association for Welding Technology (Deutscher Verband für Schweißtechnik e.V. - DVS).

In the future parts of these specifications and conditions should influence on revisions to the technical regulations and instructions for the construction of the landfill liner system. Thus the special requirements valid for the surface of the mineral layer of a composite liner must also be taken into consideration in the regulations for the installation of the mineral layer. However, installation requirements and conditions, particularly with regard to geomembrane installation and seaming, will also remain a part of future certification. In this way it is possible to react more quickly to new technical developments by consultation with the Expert Committee than it would be by revising regulations.

Several recommendations are given as a supplement to the specifications and conditions.

Independent third-party control is certainly of particular importance for quality assurance on the landfill construction site. However the local project manager and the technical supervisor have initial responsibility for expert installation in accordance with the specifications and conditions and hence avoiding defects that lead to an unsatisfactory intimate contact. For this reason the obligation that they be present during the various installation operations applies here in the same way it does for the third-party inspector.

If the geomembranes are stored for a long time at the construction site they must be protected from the effects of weather. Covering the rolls with construction paper or something similar at the construction storage site frequently gives protection that is not very durable. When longer storage times are to be expected (longer than three months), the rolls to be delivered must be provided with wrapping by the manufacturer at the factory.

According to the Lower Saxony Directive, the geomembrane installation operations (installation and seaming) should be included and inspected in setting up the test site for the mineral layer. Thus, the test sites must be large enough for the geomembranes to be installed and seamed in representative sizes. In practice, it has proved useful to "fine tune" the work of the various crafts at the test site, up to and including the installation of the drainage layer. The third-party inspector should determine case by case on the basis of his experience and in co-operation with the companies participating whether the geomembrane installation work is to be included in the test site. The designer must therefore list alternative test sites, one without and one with the installation of the geomembranes, in the requirements list of the tender.

The permitted deformations in the surface of the mineral layer, referred to in 8.3, cannot always be adhered to when the clay content and hence the water content is high. If a sufficiently plastic material of this kind is used greater unevenness may be accepted if the third-party inspector so stipulates in agreement with the technical authority. Lumps or other foreign bodies may not lie on the surface of the mineral layer since they can lead to considerable damage to the geomembrane [21]. Larger visible lumps (diameters greater than 10mm) embedded in the surface must also be removed and the impression left by them made good since damage to the geomembrane resulting from the embedded lumps depends to a great extent on the nature and quality of the mineral material. Since the Lower Saxony Directive allows soil lumps of up to 32mm in the case of a mineral material, difficulties may be caused in individual cases by larger pieces of gravel that occur in the soil. Larger particles can be avoided in advance only by careful selection and processing of the material of the upper part of the mineral layer. In part, special agricultural machines for "collecting" the larger particles in the sub-surface layer are used. As a rule the surface is scrutinized and the visible particles are removed. In any event it must be ensured that individual grains are fully embedded in the mineral layer. The surface of the mineral layer must be assessed and surface dressing measures established at the test site for the mineral layer. Here again the third-party inspector in agreement with the on-site project manager must determine how to proceed on a case-by-case basis. When the technical authority approves or possibly accepts the mineral layer, the plastics third-party inspector must be consulted for the installation of the geomembranes.

The geomembranes must lie smoothly on the surface of the mineral layer before the protective and drainage layers are installed. The large heat-expansion coefficient of the geomembranes might impede wave-free geomembrane installation, however it can and must be taken advantage of by adapting the installation process to temperature variations during the course of the day in order to achieve smoothness prior to ballasting [23]. Experienced geomembrane installers have mastered this installation process.

In order that the geomembrane can fulfill its barrier function over a long period of time, it must be protected against mechanical damage from the drainage layer which is applied subsequently and generally consists of coarse gravel. In the later phase of the landfill's existence, static mechanical loads, primarily applied at single points arise from the enormous waste burdens under the special physical, chemical and biological conditions of the landfill. However, during the installation phase of the drainage layer dynamic loads can also occur. A suitable protective layer must receive the loads and prevent perforations and other mechanical damage to the geomembranes. Binding soils, sand layers, other mineral materials, geotextiles of polymer materials such as non-woven fabrics, combinations of non-woven fabrics and fabrics or combinations of geotextiles and mineral materials are all used as protective layers. The TI Hazardous Waste requires only that the geomembranes be protected through appropriate measures and that the suitability of the materials be proved. As a regulation protective layer, the Lower Saxony Directive currently requires a non-woven fabric weighing 400g/m^2 and a sand layer at least 10cm thick to be laid on top of it. Filter stability against the coarse-gravel drainage layer

must be ensured by a geotextile. Other protective layers may be installed if they are proved to have a satisfactory load-distributing effect. In future the protective structure described in the draft LAGA notice M3 is generally to be installed as a protective layer. This requires a non-woven fabric weighing at least 1200g/m^2, onto which broken stone (0/8) and then the drainage layer (16/32mm gravel) are laid. In this connection, protective layers of non-mineral materials will be the subject of a special certification procedure in the future.

The focus of every suitability test is the proof of the long-term protective effect under landfill conditions. The load-distribution effect of the protective layer must be so great that no lasting deformation of the geomembrane will occur. An elongation of more than 0.25% will definitely produce irreversible deformations in the geomembrane. This limiting value should therefore be observed. The permitted long-term deformations of up to 3% must be reserved for subsoil subsidence and unavoidable strains during installation. In the first place, this settling within the permitted limit can only be precisely quantified with some difficulty and dubious reliability, so "remainder" deformation reserves for denting caused by the drainage layers are not as a rule known. In the second place, denting would unfavourably alter the shear resistance between the protective layer and the geomembrane.

Moreover, it must be taken into consideration that the results achieved with the test apparatus described in Section 8.7, with an elastomer base of a certain hardness beneath the geomembrane were only proved to be comparable to the results produced with mineral bases up to a test pressure of 1000kN/m^2. In the Institute for Foundation Engineering, Soil Mechanics and Energy Hydraulic Engineering (Institut für Grundbau, Bodenmechanik und Energiewasserbau - IGBE) of the University of Hannover problems arose in applications testing when the boundary conditions differed from those of the co-operative experiment of the "Quo Vadis Protective Layers" workshop. At very high pressures the results of experiments with elastomer bases were not always on the safe side compared to clay layers as a base [20]. With an acceleration factor of 1.5 and a temperature factor of 1.5 (for 40°C), acceptable landfill heights or overburden loads of around 44m or 650kN/m^2 and 30m or 450kN/m^2 are obtained. Currently, for greater landfill heights a decision has still to be made on a suitable test arrangement and test procedure in each individual case.

The material to be used in the landfill must be resistant to future hydraulic, chemical and biological attack. With protective layers made of mineral substances suitable for landfill use, such as low-calcium sand or broken stone, it is as a rule sufficient to prove the filter stability of the drainage layer. For other materials, such as combination protective layers of geotextiles and mineral substances, their chemical and biological resistance and the mechanical protective effectiveness must be proved. With regard to polymer materials, it must be considered that mechanical loading can have a significant effect on resistance to chemical attack; consequently the load-plate pressure test should be carried out under the influence of chemicals. Research projects are underway within the framework of a BMFT-sponsored Integrated Research Programme "Improvement of Landfill Liner Systems", at the Franzius Institute for Hydraulic Engineering (Franzius-Institut für Wasserbau), at the Official Testing Institute (Amtliche Materialprüfanstalt) of the University of Hannover and at BAM [18] to test possible effects and to develop a suitable modified load-plate pressure test. Until the results of these studies are available only preliminary proof of the suitability of geotextiles can be produced and in this context at least the requirements in Section 8.7 should be satisfied. In this regard the standard for resistance is the change in the characteristic values produced from index tests applying accelerated test conditions for immersion tests in various media, oven ageing tests, weathering tests and the effect of test bacteria. It is still not possible on the basis of these tests to derive any values for the life-span of a material in a landfill. We are dealing rather with the establishment of high quality standards that permit us to expect that, even in worst case scenarios, the material used will remain durable longer than the operating life

of the landfill. For the protective layers the standard must be directed toward the durability of the geomembranes: the protective effect must last at least throughout the lifetime of the geomembrane. Hence, the testing of chemical resistance should be based at least on the concentrated liquid media in the media list of the NRW guidelines. However, within the framework of the research project referred to above this list is currently being revised and a uniform test procedure adapted to geotextiles is being laid down. Moreover, because of the fibre structure of many synthetic protective layers, in particular their resistance to oxidative degradation must also be tested. An overview of the current state of requirements for protective layers of polymer materials is given in [19].

The installation of geotextile protective layers should be carried out by the geomembrane installer in order to ensure a co-ordinated installation and to avoid any damage to the geomembranes. In many cases the geotextile is joined using hot air in the area of overlap to prevent its being blown by the wind. This work must be carried out expertly and without damage to the geomembrane and is also subject to third-party control.

ART 3: LITERATURE, TABLES AND APPENDICES

15. Literature

[1] Stief K (1986) The Multibarrier Concept as a Basis for the Design, Construction, Use and Aftercare of Landfills (Das Multibarrierenkonzept als Grundlage von Planung, Bau, Betrieb und Nachsorge von Deponien). *Müll und Abfall* **1**, 15-20.

[2] Knipschild F W ed (1985) Landfill Basal Liners Using Geomembranes (Deponiebasisabdichtungen mit Kunststoffdichtungsbahnen). *Müll und Abfall* Supplement 22, Erich Schmidt Verlag, Berlin.

[3] Meseck H ed (1987) Mineral Landfill Liners (Mineralische Deponieabdichtungen). *Müll und Abfall* Supplement 24, Erich Schmidt Verlag, Berlin.

[4] First General Administrative Provision to Requirements for Ground Water Protection in the Storage and Deposition of Wastes (Erste Allgemeine Abfallverwaltungsvorschrift über die Anforderungen zum Schutz des Grundwassers bei der Lagerung und Ablagerung von Abfällen) January 31, 1990, Gemeinsames Ministerialblatt, No. 8, p. 74, 1990.

[5] Second General Administrative Provision to the Waste Avoidance and Waste Management Act. Part 1: Technical Instructions on the Storage, Chemical, Physical and Biological Treatment, Incineration and Deposition of Waste Requiring Particular Supervision, 12. March 1991. (TI Hazardous Waste), (Zweite Allgemeine Verwaltungsvorschrift zum Abfallgesetz, Teil 1: Technische Anleitung zur Lagerung, chemisch/physikalischen, biologischen Behandlung, Verbrennung und Ablagerung besonders überwachungsbedürftigen Abfällen - TA Abfall) Gemeinsames Ministerialblatt, **8**, 139.

[6] See also the Lower Saxony Directive [10] and the NRW Guidelines [11].

[7] Third General Administrative Provision to the Waste Avoidance and Waste Management Act: Technical Instructions on Recycling, Treatment and Storage of Municipal Waste, 14. May 1993. (TI Municipal Waste), (Dritte Allgemeine Verwaltungsvorschrift zum Abfallgesetz: Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen - TA Abfall.)

In the TI Municipal Waste, two classes of landfill are distinguished. With respect to geomembranes, the same requirements apply for class II landfills as in the TI Hazardous Waste. For landfills for inert materials a mineral liner alone is required (class I landfills).

[8] Stief K (1987) On the Effectiveness of Landfill Liners (Zur Wirksamkeit von Deponieabdichtungen). In: Mineral Landfill Liners (Mineralische Deponieabdichtungen), *Müll und Abfall*, Supplement **24**, 9. Ed: Meseck H, Erich Schmidt Verlag, Berlin.

[9] August H (1988) Investigations into Geomembranes (Untersuchungen über Kunststoffdichtungen). In: Deponie 2, Ablagerung von Abfällen, 375-405. Ed: Thomé-Kozmiensky K-J, EF-Verlag für Energie- und Umwelttechnik GmbH, Berlin.

August H and Tatzky-Gerth R (1990) Recent Research Results on the Barrier Effect of Composite Liners for Landfills (Neuere Forschungsergebnisse zur Sperrwirkung von Kombinationsdichtungen für Deponien). In: Fortschritte der Deponietechnik 1990, 209-226. Eds: Fehlau K-P and Stief K, Erich Schmidt Verlag, Berlin.

August H and Tatzky-Gerth R (1991) New Research Results from Long-Term Studies of Composite Liners as Technical Barriers for Landfills and Contaminated Land (Neue Forschungsergebnisse aus Langzeituntersuchungen an Verbunddichtungen als technische Barriere für Deponien und Altlasten), IBK Conference 136, Darmstadt, 6-7, November 1991, and

August H, Tatzky-Gerth R, Preuschmann R and Jakob I (1992) Permeation Behaviour of Composite Liners for Landfills and Contaminated Land with respect to Water Pollutants (Permeationsverhalten von Kombinationsdichtungen für Deponien und Altlasten gegenüber wassergefährdenden Stoffen), UFOPLAN, BMU. WASSER F+E-Vorhaben 102 03 412, Part I, BAM, Berlin.

[10] Directive 207-62812/21 of 6-24-88, Landfill Liners for Municipal Wastes (Lower Saxony Directive), which may be consulted at the Lower Saxony Ministry of the Environment. A Lower Saxony Landfill Handbook is currently in preparation.

[11] Geomembranes as Landfill Basal Liners (NRW Guideline). Issued by the Nordrhein-Westfalia Office for Water and Waste in cooperation with the Nordrhein-Westfalia Ministry for Food, Agriculture and Forests (May 1985). A notice on the deposition of municipal wastes is currently in preparation.

[12] TI Hazardous Waste, Part 1, Section 9.4.1.1 states: "Exceptions may be made to the requirements in Sections 1-3 regarding these landfill liner systems if it is proved that the alternative system is equivalent." Sections 1-3 set out requirements for composite liner.

[13] Drescher J (1988) Landfill Liners for Hazardous Waste: a Working Paper (Deponieabdichtungen für Sonderabfalldeponien: Arbeitspapier). *Müll und Abfall* **7**, 281.

[14] Friesecke G (1985) Calls for Tenders for Landfill Basal Liners Made of Geomembranes (Die Ausschreibung von Deponiebasisabdichtungen aus Dichtungsbahnen), In: Deponiebasisabdichtungen mit Kunststoffdichtungsbahnen. Müll und Abfall, Supplement **22**, 17. Ed: Knipschild F W, Erich Schmidt Verlag, Berlin.

[15] August H (1988) Requirements for Geomembranes in Landfill Liners (Anforderungen an Kunststoffdichtungsbahnen in Deponieabdichtungssystemen). In: Fortschritte der Deponietechnik 1988, 97-110. Eds: Fehlau K-P and Stief K, Erich Schmidt Verlag, Berlin.

[16] Koch R, Gaube E, Hessel J, Gondro Ch and Heil H (1988) Long-Term Durability of Polyethylene Geomembranes for Landfills (Langzeitfestigkeit von Deponiedichtungsbahnen aus Polyethylen). *Müll und Abfall* **8**, 3.

[17] John P and Koch R Long-Term Durability of Weld Bonds in HDPE Geomembranes (Langzeitfestigkeit von Schweißverbindungen an Dichtungsbahnen aus HDPE), DVS Reports, Volume 111.

[18] Integrated Research Programme, The Improvement of Landfill Liner Systems (Verbundvorhaben Deponieabdichtungssysteme), Proceedings of the First Conference, September 1991, available from Prof H August, Department 8.3. Landfill and Remedial Engineering, BAM, Unter den Eichen 87, D-12205 Berlin.

[19] Müller W and Müller U (1992) Certification of Synthetic Components for Landfill Liner Systems: Geomembranes and Protective Systems (Zulassung von Kunststoffkomponenten für Deponieabdichtungssysteme: Dichtungsbahnen und Schutzsysteme). In: Proceedings of the Eighth Conference; The Secure Landfill (Die sichere Deponie), South German Centre for Plastics (Süddeutsches Kunststoffzentrum), Würzburg.

[20] Brummermann K and Blümel W University of Hannover, Institute for Foundations, Soil Mechanics and Energy Hydraulic Engineering (Institut für Grundbau, Bodenmechanik und Energiewasserbau IGBE), private communication.

[21] Schicketanz R (1990) Test Report on the Effect of the Mineral Layer on the Polymer Liner of a Composite Liner (Versuchsbericht über den Einfluß der mineralischen Dichtungsschicht auf das Polymere Dichtungselement in einer Kombinationsdichtung), Report for the Kreis Olpe, Schicketanz Consultant Engineering.

[22] Assessment of the Long-term Behaviour of the Weld Seams of Geomembranes for Basal Liners and Landfill Cappings. Research Report (1992). (Beurteilung des Langzeitverhaltens der Fügenähte von Kunststoffdichtungsbahnen zur Basis- und Oberflächendichtung bei Deponien), BMFT Integrated Research Programme FKZ 1470486, South German Centre for Plastics (Süddeutsches Kunststoffzentrum), Würzburg.

[23] Schicketanz R (1992) The Functioning of Composite Liners and Requirements for the Mineral Surface (Wirkungsweise der Kombinationsdichtung und Anforderungen an die mineralische Oberfläche). *Müll und Abfall* **5**, 287.

16. Requirements Tables

Table 1: General physical requirements (HDPE geomembranes)

Property	Characteristic	Standard values	Test methods, Testing regulations
1. Appearance			
1.1	Surface	Closed surface, free of scratches, bubbles and pores, no damage.	Visual assessment in accordance with DIN 16726, Sec. 5.1.
1.2	Homogeneity of material	Free of pores, lumps, foreing inclusions.	Visual assessment in accordance with DIN 16726, Sec. 5.1.
1.3	Carbon black content	The content by weight of carbon black must be between 1.8 and 2.6%. The value set out in the certificate must be maintained to within a tolerance of 10%.	Thermogravimetric analysis or determination in accordance with ASTM 1603-76 (see Appendix A).
1.4	Homogeneity of carbon black distribution	See Appendix A.	See Appendix A.
1.5	Straightness	Maximum distance of geomembrane edge from straight edge ≤50mm in a section 10m long of an unrolled 12m section of geomembrane.	Determination of straightness in accordance with DIN 16726, Sec. 5.2.
1.6	Flatness	Maximum distance of undulating geomembrane from plane base ≤50mm in a section 10m long of an unrolled 12m section of geomembrane.	Determination of flatness in accordance with DIN 16726, Sec. 5.2.

Property	Characteristic	Standard values	Test methods, Testing regulations
2. Thickness of geomembrane			
2.1	Nominal thickness and mean value	Thicknesses of 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 should be used as nominal thicknesses. The arithmetical mean of the thickness measurements must always be than the nominal thicknesses.	Under DIN 16726, the thicknesses will be determined in accordance with DIN 53353. Samples will be taken over the entire extent of geomembrane at distances of 0.2m.
2.2	Individual values	The least thickness shall be 2.50mm. At a nominal thickness of 2.50mm, the individual values must therefore be ≥2.50mm, the individual value = normal thickness -0.0/+0.3mm. At other nominal thicknesses individual value = nominal thickness ±0.2mm holds.	
3. Density		For resin densities without carbon black between 0.932 and 0.942g/cm^3, the allowable densities for the geomembrane can be obtained depending on carbon black content.	Determination in accordance with DIN 53479, Procedure A, see Table 5,1.
4. Melt index and viscosity			
4.1	Change of melt index while processing resin into geomembrane	The following must apply: ΔMFI ≤0.2g/10min, 190/5, ΔMFI ≤2g/10min, 190/21.6. ΔMFI = MFI (e) – MFI (a).	Determination of melt index 190/5 or 190/21.6 in accordance with DIN 53735 on resin (MFI (a)) and on a sample from geomembrane (MFI (e)).
4.2	Change of viscosity number while processing resin into geomembrane	No significant change due to processing	DIN 53728, Part 4.

Property	Characteristic	Standard values	Test methods, Testing regulations
5. Oven ageing performance			Oven ageing in accordance with DIN 16726, Sec. 5.13.1. at 80°C.
5.1	Change of dimension along and across the direction of extrusion	Maximum relative change of dimension after 112 days of oven ageing must be less than 1% along and across the direction of extrusion.	Determination of change of dimension in accordance with DIN 53377 after 7, 28, 56, 112 days of oven ageing. Samples are taken across the width of geomembrane at 1m intervals.
5.2	Change in external properties	No change, see 1., especially no bubbles	See 1.1 and 1.2, period of oven ageing 112 days.
5.3	Change in mechanical properties (yield stress, elongation at yield and elongation at break)	Relative change of yield stress and elongation at yield ≤10%. Elongation at break >400% [*].	Tensile tests in accordance with DIN 53455, see 8.2, period of oven ageing 112 days.
5.4	Change in stress crack resistance	After oven ageing the samples must pass the stress crack test, see 15.	Stress crack test, see Table 3, 15.
5.5	Change of folding behaviour at low temperatures	No failure in accordance with DIN 53361.	Determination of folding behaviour in accordance with DIN 53361, across and along the direction of extrusion.
5.6	Change of dimensions in short-term, strong heating	The maximum relative change of dimension must be ≤1% both across and along direction of extrusion.	Determination of the change of dimension in accordance with DIN 53377 after conditioning for 1 hr at 120°C.

Property	Characteristic	Standard values	Test methods, Testing regulations
6. Weathering performance		See Appendix A.	At a carbon black content >1.8% by weight the test for HDPE geomem-branes can usually be omitted. For test method see Appendix A.
12. Permeation of hydrocarbons (watertightness) 7.1 7.2	Rates of permeation for trichloroethylene. Rates of permeation for acetone	Rate of permeation at 23°C $<80g/m^2$ d Rate of permeation at 23°C $<0,5g/m^2$ d	Measurement at steady state, 23°C, 80mm active sample diameter and 2.5mm sample thickness. At rates $>3g/m^2$ d in accordance with DIN 53532, otherwise by more sensitive methods, see Appendix A.

* For textured geomembranes the allowable elongation at break will be determined on a case-by-case basis.

Table 2: Special physical and mechanical requirements (HDPE geomembranes)

Property	Characteristic	Standard values	Test methods, Testing regulations
8. Performance under tensile load 8.1	Biaxial tensile test, out-of-plane elongation	Out-of-plane elongation ≥15% without yielding of the material.	The test is based on DIN 53861, see Appendix A.
8.2	Uniaxial tensile test, yield stress, elongation at yield, elongation at break at 23°C	The following values must apply at 23°C: yield strength ≥15N/mm², elongation at yield ≥10%, elongation at break ≥400%.*	The tensile tests are carried out in accordance with DIN 53455 with No. 3 samples at a climate of 23/50 and at 70 ± 2°C at speed of 50mm/min. The samples are taken from the edge of the geomembranes along and across the direction of extrusion.
8.3	at 70°C	The following values must apply at 70°C: yield strength and elongation at yield: still to be determined. Stress ≥2N/mm² at 5% elongation.	
9. Tear propagation resistance	Tear propagation strength	Tear propagation strength ≥500N. Tear propagation strength ≥300N.	Testing in accordance with DIN 53356-A. Testing in accordance with DIN 53515. Samples taken along and across the direction of extrusion.
10. Resistance to punctiform quasi-static single loads	Penetration strength	Penetration strength ≥6000N.	Testing in accordance with DIN 54307 at a punch speed of 50mm/min.
11. Perforation test	Mechanical resistance to perforation	No failure of watertightness at the point tested	Testing in accordance with DIN 16726, Sec. 5.12, drop height 2000mm.
12. Performance at low temperatures	Brittleness in the cold	No failure at –20°C in accordance with DIN 53361	Folding the test in the cold along and across the direction of extrusion in accordance with DIN 53361.

Property	Characteristic	Standard values	Test methods, Testing regulations
13. Relaxation performance	Drop in stress in the time-stress curves	After 1000 hours the stress must be ≤50% of the stress after 1min.	In accordance with DIN 53441 the drop in stress is measured at a constant elongation of 3% over time (climate: 23/50) along and across the direction of extrusion.
14. Seam strength 14.1	Short-term shear test, failure performance	No shearing off of the seam, significant yielding of base material near to but outside the seam.	Samples taken and test conducted in accordance with DIN 53441, sample A, tensile test in accordance with DIN 53455, speed 50mm/min, see also DVS 2203, part 2.
14.2	Peeling test, failure performance	No peeling off of the seam, significant yielding of the base material near to but outside the seam.	Following DIN 16726, Sec. 26.1, see also DVS 2203, peel test, draft, speed 50mm/min.

* For textured geomembranes the allowable elongation at break will be determined on a case-by-case basis.

Table 3: Requirements with respect to combined physical and chemical attack (HDPE geomembranes)

Property	Characteristic	Standard values	Test methods, Testing regulations
15. Stress crack resistance	Change in tensile strength	After 112 days of immersion residual tensile strength must be ≥90%.	Test as in pin impression test following DIN 53449 for the evaluation of environmental stress cracking, ball or pin impression method, see Appendix A. The relative residual tensile strength is the ratio of the tensile strength of the immersed, pin-tested sample to the tensile strength of the sample that has only been pre-immersed and not pin-tested.
16. Long-term performance of the weld seam	Still to be determined	Still to be determined	Still to be determined
17. Stress crack resistance of the weld seam	Still to be determined	Still to be determined	Still to be determined
18. Internal pressure creep test; time-dependent creep strength of pipes	Reference stress-time curves	An extrapolation of the reference stress-time curves obtained on the basis of DIN 8075 at higher temperatures (eg 60°C, 80°C) must indicate that no failure is to be expected at a stress of $5N/mm^2$ at 40°C in 40 years (3.5×10^5 hours). For extrapolation see DIN 16887.	Long-term internal pressure test in accordance with DIN 8075 on pipes made from the same resin as the geomembrane.

Table 4: Chemical and biological requirements for geomembranes

Property	Characteristic	Standard values	Test methods, Testing regulations
19. Resistance to highly concentrated liquids			
19.1	Change in weight	Immersion must be carried out up to constant weight.Tensile test is then conducted on re-dried samples.	DIN 53521, concentrated media, on the basis of Appendix 1, Group A of the NRW Guidelines. Immersion temperature 23°C, for HDPE geomembrane the media 6, 7, 10 and 11 may be omitted, see Appendix A.
19.2 Changes in mechanical properties	Uniaxial tensile test, yield stress, elongation at yield	Change in yield stress <10% and in elongation at yield <10%.	The tensile tests are carried out according to DIN 53455 with No. 3 samples of the geomembrane at a climate 23/50 and a speed of 50 mm/min.
20. Resistance to microorganisms			
20.1	Change in weight	≤5%	DIN 53739, Procedure D soil burial test in microbe-active soil, length of test 1 year.
20.2	Visual assessment	No significant changes	
20.3	Changes in mechanical properties	Changes ≤10%.	Tensile test in accordance with DIN 53455, see Table 2, 8.2.
21. Resistance to higher plant life	Root strength	No penetration by roots	Following DIN 4062, Sec. 5.7, the tests are carried out on the base material and on the weld seams.
22. Resistance to higher animal life	Resistance to burrowing animals	Not to be gnawed through or nibbled by animals.	Test method explained in BPG Geomembranes, IFBT, 1982, p. 38, Sec. 3.8 and 4.8. Tests are carried out at MPA Dortmund using Arvicola Terrestris (water vole).

Table 5: Requirements on HDPE resin within the framework of quality assurance

Property	Test method	Sample material	Requirements and tolerances
1. Density (pigmented)	DIN 53479, Procedure A	Melt cord from melt index determination on the granulate, temper 1 hr. at 100°C or press board in accordance with DIN 16770, Part 1, Procedure B.	As set out in the certificate
2. Melt index (190/5 or 190/21.6)	DIN 53737	Granulate	As set out in the certificate
3. Carbon black content and distribution	See Table 1, 1.3, 1.4	Press board from granulate in accordance with DIN 16770, Part 1, Procedure B*.	As set out in the certificate
4. OIT value	ASTM standard or factory instructions	Granulate	As set out in the certificate
5. Viscosity number	DIN 53728, p. 4	Granulate	As set out in the certificate

*In the evaluation of the carbon black content of the granulate, lumps and bubbles are not to be considered.

Table 6: Test methods and requirements within the framework of quality control of the manufacture of HDPE geomembranes

Property	Test method	Frequency	Requirements and tolerances
1. Thickness	See Table 1, 2	At least every 10 running metres. In case of continuous automatic measurement of thickness, control measurement on each roll.	As set out in the certificate
2. External appearance	See Table 1, 1.1, 1.2	Regular evaluation of the homogeneity of the material at least every 200 running metres.	See Table 1, 1.1, 1.2
3. Straightness and flatness	See Table 1, 1.5, 1.6	Start of every production run and at least every 500 running metres.	See Table 1, 1.5, 1.6
4. Carbon black content and homogeneity of the distribution	See Table 1, 1.3, 1.4	Start of every production run and at least every 200 running metres. The test is dropped if the resin meets the requirements.	As set out in the certificate; see Table 1, 1.4
5. Change in dimensions	See Table 1, 5.6	At least every 200 running metres, samples from the edges and middle of the geomembrane.	See Table 1, 5.6
6. Change in melt index	See Table 1, 4.1	Start of every production run and at least every 500 running metres.	As set out in the certificate
7. Yield stress, elongation at yield and elongation at break	See Table 2, 8.2	Start of every production run and at least every 200 running metres.	As set out in the certificate

Table 7: Test methods and requirements within the framework of third-party control of the manufacture of HDPE geomembranes

Property		Test method	Requirements and tolerances
1.	Density	See Table 5, 1.	As set out in the certificate
2.	Thickness	See Table 1, 2.	As set out in the certificate
3.	External appearance	See Table 1, 1.1, 1.2.	See Table 1, 1.
4.	Straightness and flatness	See Table 1, 1.5, 1.6.	See Table 1, 1.5, 1.6.
5.	Carbon black content and homogeneity of carbon black distribution	See Table 1, 1.3, 1.4.	Carbon black content, see certificate. Homogeneity, see Table 1, 1.4.
6.	Change in dimensions	See Table 1, 5.6.	See Table 1, 5.6.
7.	Change in melt index	See Table 1, 4.1.	As set out in the certificate
8.	Multiaxial tensile test, out-of-plane test	See Table 2, 8.1.	As set out in the certificate
9.	Uniaxial tensile load (yield stress, elongation at yield, elongation at break)	See Table 2, 8.2 and 8.3.	As set out in the certificate
10.	Tear propagation resistance	See Table 2, 9.	As set out in the certificate
11.	Stamp penetration test	See Table 2, 10.	As set out in the certificate
12.	Perforation test	See Table 2, 11.	See Table 2, 11.
13.	Folding at low temperatures	See Table 2, 12.	See Table 2, 12.

APPENDIX A

TEST PROCEDURE SPECIFICATIONS

1. Carbon Black Content (Table 1, 1.3)

The carbon black content is determined through thermogravimetric analysis (TGA). The polyethylene in the carbon-black-containing sample is pyrolized in a nitrogen atmosphere at increasing temperatures and the remaining carbon black is burned under an oxygen supply. A microscale continuously measures the loss of mass. Negligible amounts of residue are produced in this test (<0.05% by weight). The proportion of carbon black can be determined through standard evaluation of the mass-change/temperature curve. At least three individual measurements should be carried out.

The parameters for performing a test at BAM with a Mettler thermoscale of the TA 3000 system are as follows. A sample weighing 20mg to 50mg, rammed out of the geomembrane, is weighed in a 150µl Al_20_3 crucible. It is immersed at below 600°C in 200ml/min of nitrogen and after that in 200ml/min of synthetic air. The start temperature is 30°C and the end temperature is 900°C. Before each series of measurements, a blind curve is taken to correct for buoyancy. This forms part of the test report, along with the measurement curves.

2. Homogeneity of Carbon Black Distribution (Table 1, 1.4)

Testing of the homogeneity of carbon black distribution is carried out on the basis of guideline R 1.3.2., "HDPE pressure pipes", of the Synthetic Pipe Association, Section 3.1.1.3. A microtome slice approximately 10µm thick is taken from each of three samples from the cross section, randomly distributed over the geomembrane. At a magnification of 100x the microtome slices are examined to ascertain the homogeneity of carbon black distribution and any defects. An area of at least $100mm^2$ is covered.

The quantitative requirements of this guideline are not adequate, hence a qualitative assessment must still take place. However, a quantitative boundary condition is that in no case may carbon black clusters and streaks of poorly mixed areas or defects such as bubbles and lumps over 50µm in size be present.

A qualitatively good homogeneity of distribution exhibits no bands of carbon black or naturally coloured material, no streaks of poorly mixed areas and no clusters of carbon black or flecks of naturally coloured material. At worst, fine flecks of carbon black (up to about 30µm in diameter) will be distributed over the uniformly grey-pigmented surface. Figure 1 shows examples of distributions in certified geomembranes, Figure 2 gives examples of non-homogeneity in distributions which do not satisfy the requirements.

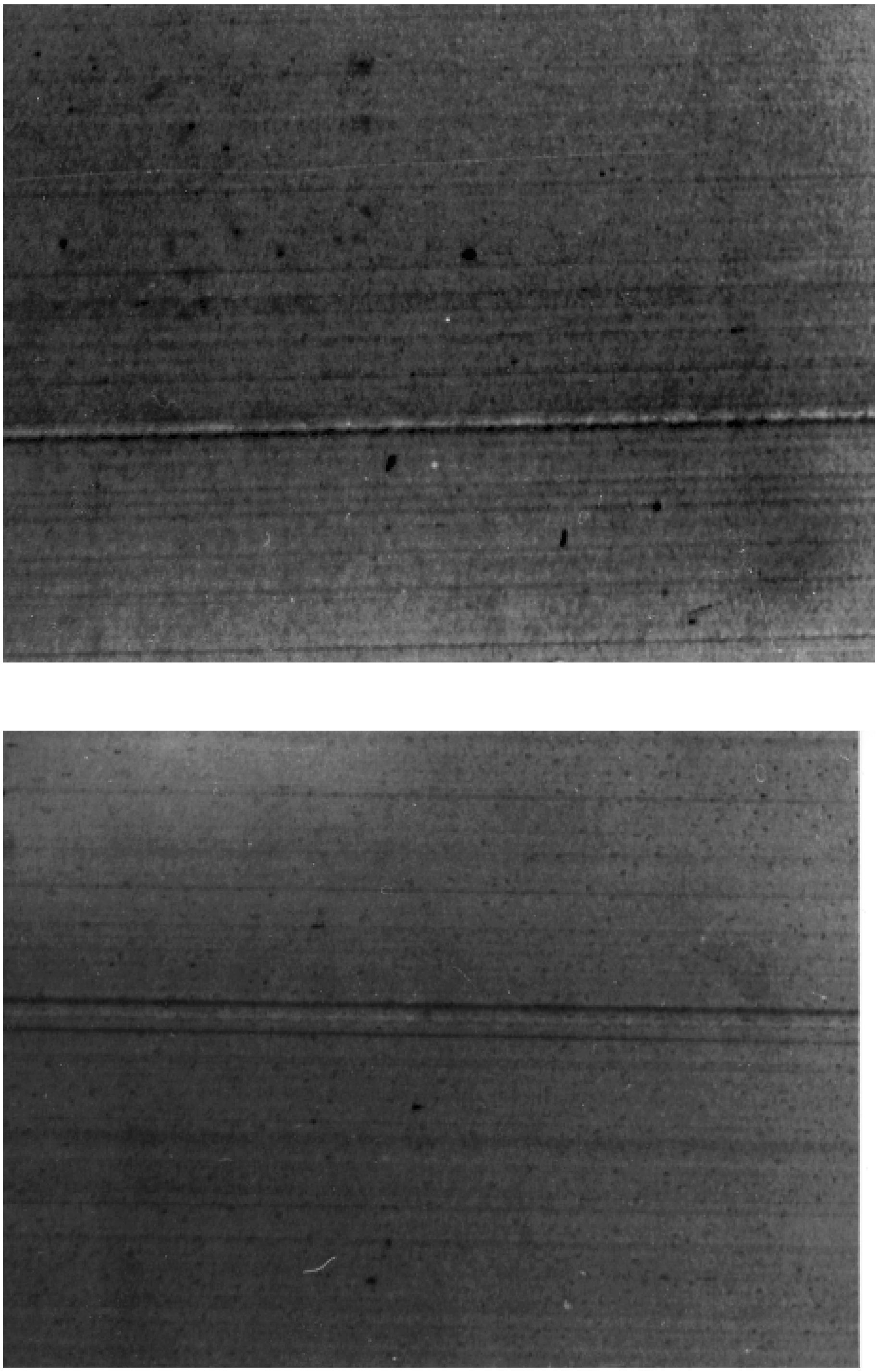

Fig 1. Required homogeneity of carbon black distribution (microtome section, 100x magnification)

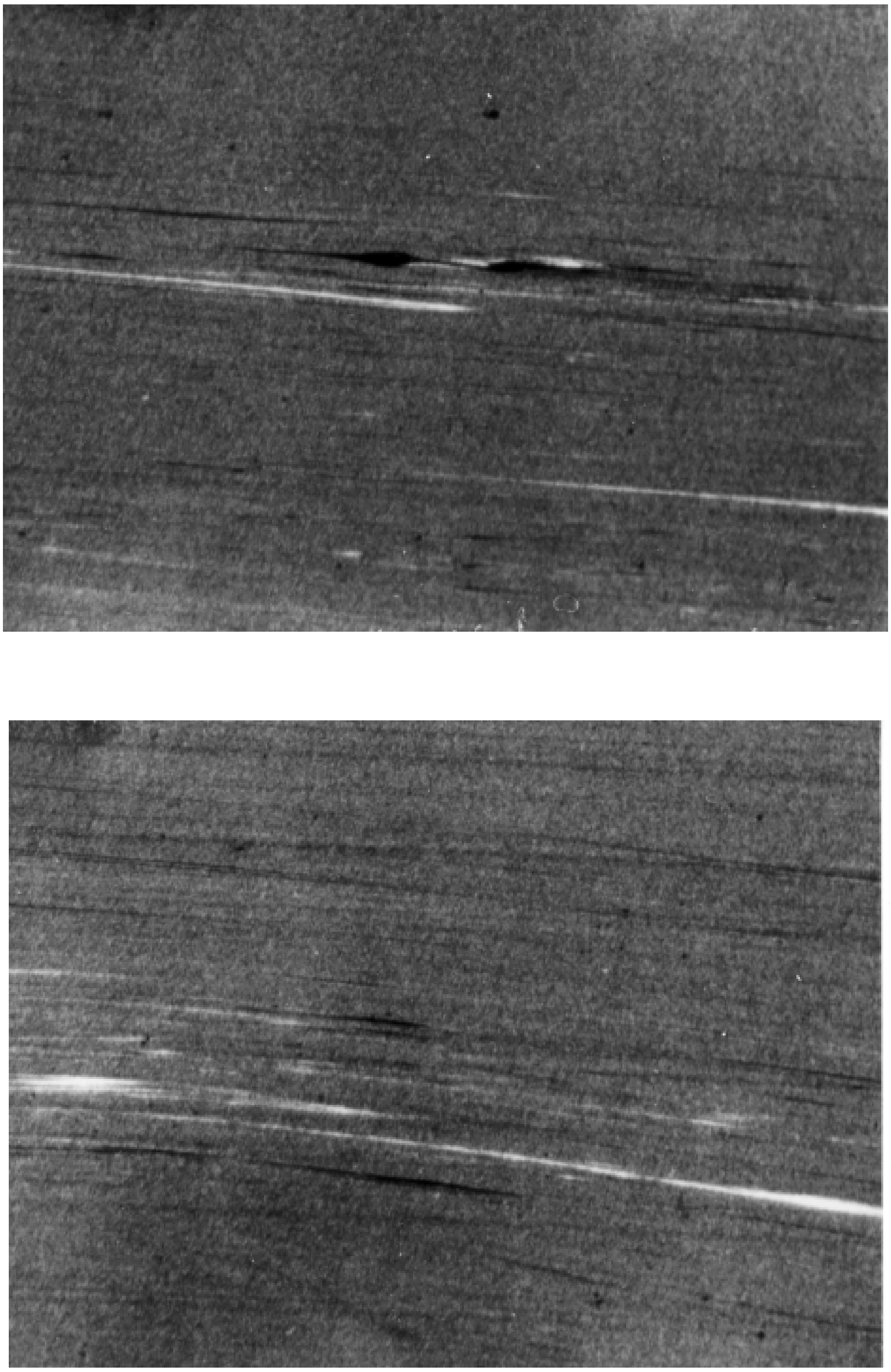

Fig. 2. Inadmissible non-homogeneity of carbon black distribution (microtome section, 100x magnification).

3. Thickness of the Geomembrane (Table 1, 2.)

In geomembranes with textured surfaces and discontinuities of thickness due to manufacturing conditions the thickness of the geomembrane should be assessed optically. For this purpose the cross section of the geomembrane can be evaluated in, for example, a profile projector (10-20 times magnification, accuracy of mechanical positioning 1μm). The thinnest spot in the profile is identified and measured. For this purpose distribution curves of thickness measurements along the profile are sometimes to be assessed. Each individual measurement must exceed 2.50mm. Within the framework of the certification, the positioning and method of the thickness measurements may be decided upon in the third party and quality control on a case-by-case basis.

4. Weathering Test (Table 1, 6.)

The test for weather resistance may be carried out by open-air weathering for at least two years or through artificial weathering with an exposure period that corresponds to two years of open-air weathering. Artificial weathering is carried out in accordance with DIN 53384, within the spectrum of Procedure B. The weathering cycle runs as five hours of dry weather and one hour of rain. The test weather during the dry phase is 35°C and 40% relative humidity. The period of weathering totals 720 hours. The mechanical characteristic values (tensile test, Table 2, 8.2) and characteristic values of material properties determined on a case-by-case basis (stress crack resistance, Table 2, 15, resistance to thermal oxidative deterioration) must not be significantly altered (20% for the mechanical characteristic values) by the weathering.

5. Permeation Tests (Table 1, 7)

<u>5.1 Gravimetric Measurement</u>

Permeation by hydrocarbons in normal atmosphere (23/50) in the case of single-component-systems and with a permeation rate of >3g/m^{2}d can be measured gravimetrically, following DIN 53532.

The equipment consists of cylindrical test containers (cells) made of aluminum or other suitable light material which are open at one end, which is then sealed gas-tight with the sample, a circular segment of the geomembrane. In BAM an aluminum pot with a screw top is used as a test container. The flange on the pot is provided with three sealing ribs which are staggered with respect to two sealing ribs on the sealing flange in the lid. The capacity should be about 150ml. The depth and degree of filling of the cells should be designed in such a way that samples which are markedly buckled as a result of swelling are still completely covered by the test liquid. The induction time and permeation rate are determined from measurements of the permeated mass of the material over time (equalizing line) in the steady phase.

Even if low rates are to be expected the determination can still be made gravimetrically over a very long measurement period. However if the rates are very low (<0.001g/m^{2}d), the so-called "vacuum method" should be used.

<u>5.2 "Vacuum Method" for Determining the Permeation Rate</u>

If the rates are <0.001g/m^{2}d or a multicomponent mix is present the permeation rate is measured using the so-called "vacuum method". The design of the permeation measurement cell, the overall measurement apparatus and quantitative determination of the permeation rates are to be taken from the research report "Study of permeation performance of commonly used commercial geomembranes as landfill basal liners against leachate, organic solvents and their aqueous solutions", Report No. 103 02 208, Abfallwirtschaft (Waste Management), under contract to the Federal Environmental Agency, February 1984, pp. 30-41.

In the "vacuum method", the permeated material is suctioned off into a cold trap through a slight vacuum, where it is frozen. The cold trap is a Dewar flask which is cooled using liquid nitrogen. From time to time the cold trap is thawed, the permeated material is removed with ethanol and its mass determined quantitatively using gas chromatography.

6. Performance under Tensile Load (Out-of-Plane Test) (Table 2, 8.1.)

The performance of geomembranes when subjected to a multiaxial tensile load is tested in an out-of-plane test on the basis of DIN 53861. Samples are conditioned by storing them at normal atmosphere and the test is conducted at a temperature of 21°C – 25°C. For the purpose of the test the samples are fastened tightly between clamping devices in such a way that a free circular area 800mm - 1000mm in diameter is tested. Loading is carried out using air or flowing room-temperature water as the pressure-transmitting medium. When using water, air cushions beneath the geomembrane must be avoided. The pressure is raised in 20kPa steps and each stage is held for 2 minutes. The test should be continued until a clear local yielding (flow) of the deformed sample is reached. In accordance with DIN 53861, the arch elongation ε_b is determined from the arch height h reached before stretching and from the free clamped-in radius r. It holds:

$$\varepsilon_b = (\text{arc}\ \alpha / \sin \alpha) - 1, \text{ where } \sin \alpha = 2rh/(r^2+h^2) \text{ and arc } \alpha = (2\pi/360)\alpha$$

The arch elongation $\varepsilon_b = \Delta b/b$, $\Delta b = b - 2r$, can also be determined through direct measurement of the change in arch length b. The arch elongation must be at least 15%.

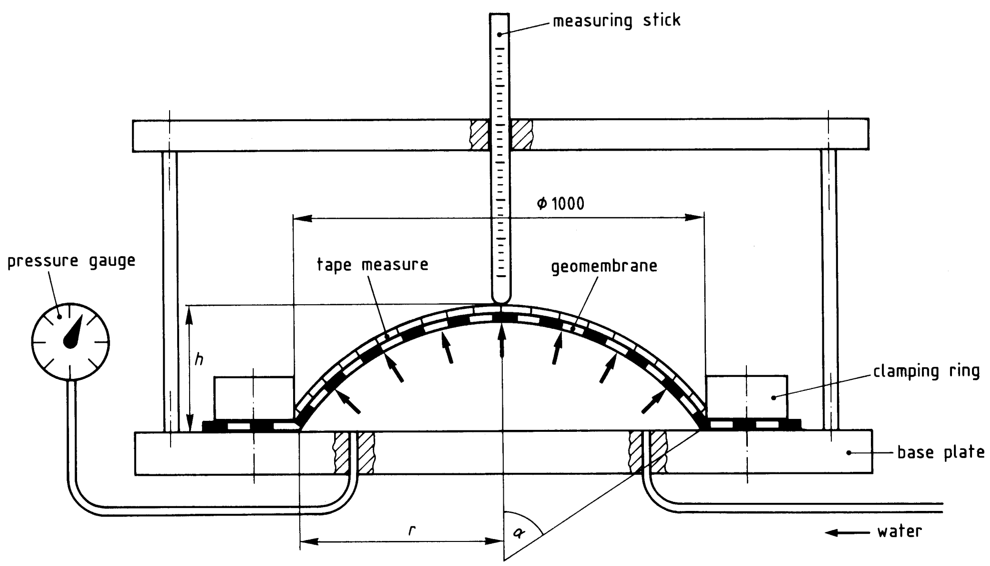

Fig. 3. Schematic diagram of out-of-plane test apparatus (Source: Schicketanz Consultant Engineering, Official Materials Testing Institute, Hannover)

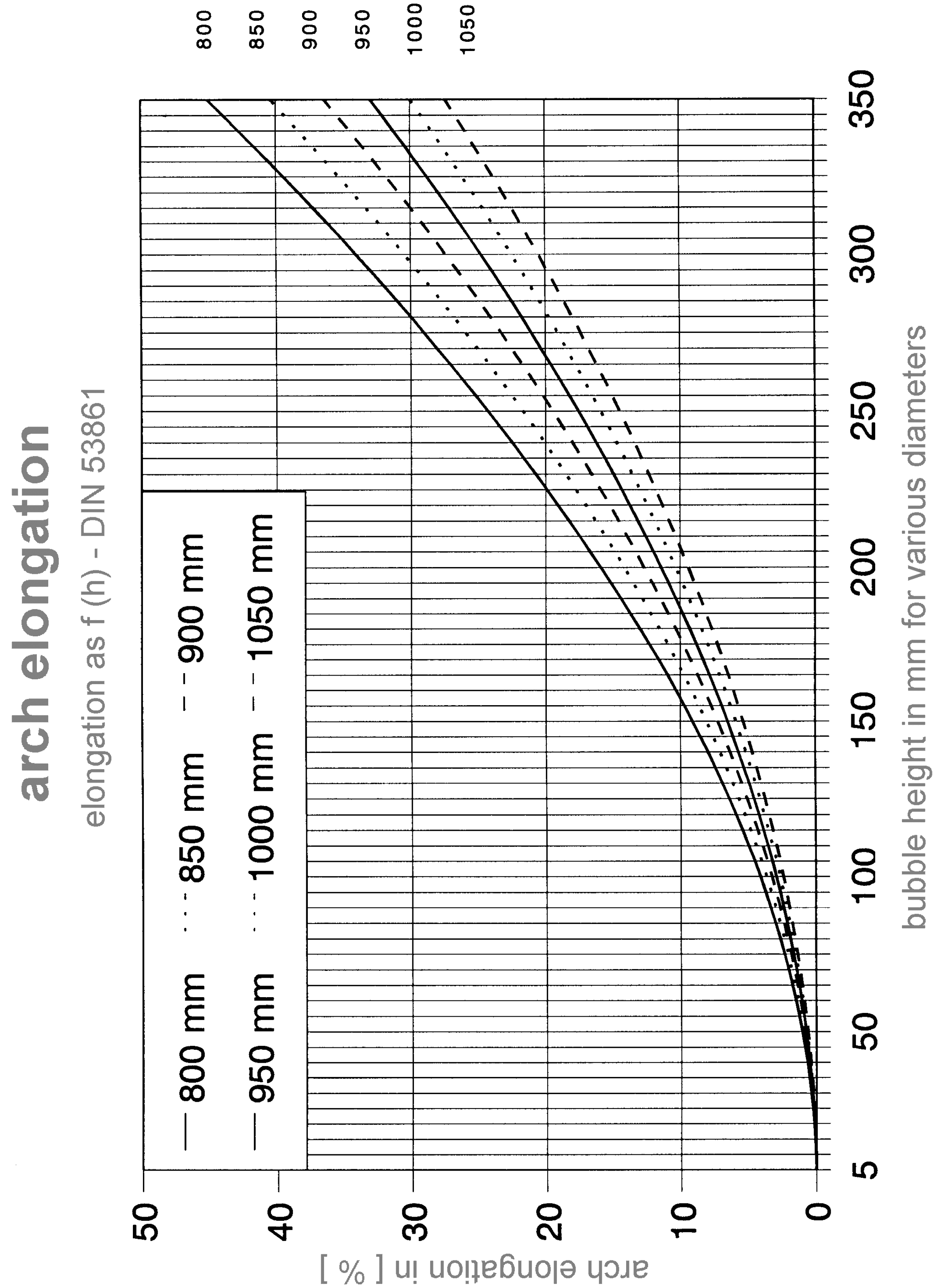

Fig. 4. Arch elongation for various arch heights and internal diameters of the testing apparatus

7. **Stress Crack Resistance** (Table 3, 15.)

7.1. Test Method

The test is carried out in accordance with DIN 53449, evaluation of environmental stress cracking, ball or pin impression method. Using the pin impression method it is possible to test the stress crack resistance of a high-density, high-molecular-weight polyethylene material with respect to wetting agents or other media. The samples are holed and notched and immersed into the study medium. After the sample has been pre-immersed, a pin of defined oversize is pressed into the hole. Samples prepared in this way are then immersed in the medium, removed after differing periods of immersion and studied for the formation of stress cracks by determining the relative residual tensile strength as a function of immersion time or up until the time the samples split apart. The relative residual tensile strength is defined as the ratio of the tensile strength of the immersed and pinned sample to the tensile strength of the pre-immersed-only samples.

The tests for stress crack resistance of geomembranes are carried out in a 5% solution of a wetting agent. Ten samples are used for each immersion period to assess the residual tensile strength, the immersion periods being 56, 112, 224 and 448 days. The dimensions of the 4mm-thick pins are described in Figure 5. The pin material used is stainless steel (eg, X12CrSi17).

7.2 Production of the Samples

The shape and size of the samples is to be taken from Figure 6. The dimensions of the samples should not differ from each other by more than ±15%. If the samples are produced by machining, with regard to the quality of the cut surface a saw cut will suffice. Any fins produced in making the sample should be removed from cut surfaces to be notched. The samples are to be notched parallel to the direction of extrusion. A hole 2.8mm in diameter is bored in each test sample and is reamed out to a diameter of 3.0^{H7}mm. In accordance with Fig. 6, the sample is then notched using a sharp razor blade. The distance between the lower end of the notch and the edge of the hole is 5mm ±0.1mm.

7.3 Conditioning of the Samples

The test samples prior to insertion of the pins and the control samples are stored in the wetting agent for 21 days at 40°C ±1°C. After they are removed, the maximum tensile strength of the control samples is determined (see 7.4, conduct of the test). In the samples that are to be further immersed the pin is pressed, point first, perpendicularly into the hole in the sample. Porous bronze plates between the samples prevent them from doming.

7.4 Conduct of the Test

The prepared samples are subsequently immersed in the test liquid tempered at 40°C and kept in a warming cabinet at 40°C ±1°C. After the required period of time, the samples are removed from the container and washed with distilled water to remove test liquid residues. This process also cools them. The pin is then removed. A saw cut is used to bisect the samples through the centre of the hole and parallel to the notched edge. Only the notched parts of the samples are used for further testing.

No later than 8 hours after being removed from the test liquid this portion of each sample is placed in a tensile-strength testing machine and subjected to a uniaxial tensile load at a test speed of 20mm/min until it breaks. The tensile test takes place at normal atmosphere (23/50) in accordance with DIN 53455. The tensile strength (maximum force/cross-section of the sample) is determined for each sample.

7.5 Evaluation

For each test period the mean value of the tensile strength for the control samples and the immersed samples is determined. The relative residual tensile strength is calculated as the ratio of the mean value of the tensile strength of the immersed samples to the mean value for the control samples. There should still be no significant change in the relative residual tensile strength after 112 days immersion (relative residual tensile strength >90%).

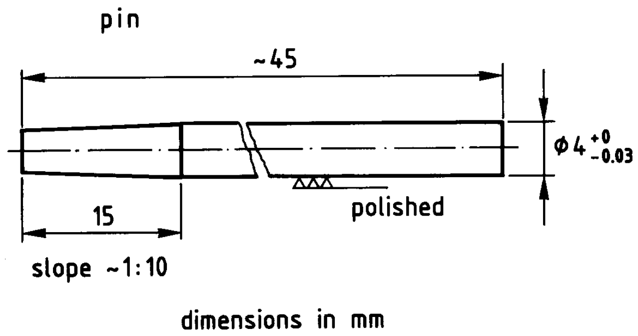

Fig. 5. Dimensions of he steel pin

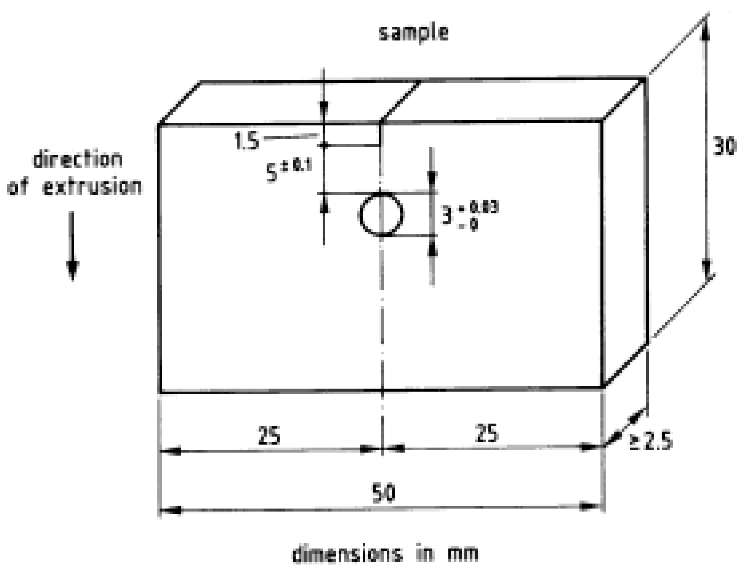

Fig. 6. Dimensions of the sample

8. Chemical Resistance (based on the NRW Guidelines) (Table 4,19)

Chemical resistance is determined through immersion tests in accordance with ISO 175 and DIN 53521. Changes in the standard values, mechanical strength (yield stress and elongation at yield in the tensile test, Table 2, 8.2) and changes in mass are determined. Selection of test liquids is as per the NRW Guidelines, Group A, highly concentrated liquid media (see below). The periods of immersion are one week, four weeks and three months and the immersion temperature is 23°C. The standard values are determined directly after immersion and in addition, for samples stored for three months, after redrying (5 days at 50°C and 2 days at 23°C in a vacuum drying chamber). If on the basis of the data significant changes in mass are still to be expected after three months of immersion the immersion tests should be continued. Immersion must not produce any significant change in external appearance (see Table 1, 1). The characteristic mechanical values must not change by more than 10% in the course of immersion and redrying. In the case of those samples placed in swelling media which only recover sufficient mechanical strength after redrying, OIT measurements should be used to clarify the extent to which stability to thermal oxidative degradation has been impaired.

In the following list of test media drawn from the NRW Guidelines, benzene is replaced on technical grounds by equal parts of toluene and xylene.

Number	Material group	Composition of test liquids
1	Petroleum (Otto fuels) and aromatic hydrocarbons	40% by volume 2, 2, 4-trimethylpentane (isooctane) 30% by volume methylbenzene (toluene) 20% by volume dimethylbenzene (xylene) 10% by volume methylnaphthalene
2	Heating oils, diesel fuels, paraffin oils and lubricating oils	35% by volume diesel fuel 35% by volume paraffin oil (C_{10} - C_{20}) 30% by volume HD 30 lubricating oil
3	Amines	40% aqueous solution of dimethylamine
4	Alcohols	30% by volume methanol 30% by volume propanol-(2), (isopropanol) 40% by volume ethandiol-(1, 2), (glycol)
5	Aliphatic hydrocarbons	30% by volume trichloroethene (trichloroethylene) 30% by volume tetrachloroethene (tetrachloroethylene) 40% by volume dichloromethane (methylene chloride)
6	Aliphatic esters and ketones	50% by volume ethane acid ethyl ester (ethyl acetate) 50% by volume 4-methyl-pentanol-(2) (methyl isobutyl ketone)
7	Aliphatic aldehydes	37% by volume aqueous solution of methanal (formaldehyde)
8	Organic acids	50% by volume ethanoic acid (acetic acid) 50% by volume propanoic acid (propionic acid)
9	Inorganic mineral acids (oxidizing)	50% by volume sulphuric acid (95-97%) 50% by volume nitric acid (65%)
10	Inorganic bases	60% caustic soda solution
11	Inorganic neutral salt solution	Saturated $NaCl/Na_2SO_4$ solution (ratio 1:1)

APPENDIX B

LIST OF STANDARDS AND GUIDELINES

Standard No.:	Title:	Date of publication:
DIN ISO 175	Determination of Behaviour with regard to Fluids including Water	April 1989
ASTM 1603-76	Standard Test Method for Carbon Black Olefinic Plastics	reapproved 1988
DIN 4062	Jointing Materials for Concrete Structural Components (Cold-worked Plastic Jointing Materials for Sewers and Sewage Pipes) (Requirements, tests and processing)	Sept. 1978
DIN 8075	High-Density Polyethylene (HDPE) Pipes (General quality requirements, testing)	May 1987
DIN ISO 9000	Manual for the Selection and Utilization of the Standards for Quality Management, Elements of a Quality System and for Quality Assurance	May 1987
DIN ISO 9001	Quality Systems - Model for Quality Assurance in Design/Development, Production, Installation and Servicing	May 1987
DIN ISO 9002	Quality Systems - Model for Quality Assurance in Production and Installation	May 1987
DIN ISO 9003	Quality Systems - Model for Quality Assurance in Final Inspection and Testing	May 1987
DIN ISO 9004	Quality Management and Quality System Elements (Guidelines)	May 1987

Standard No.:	Title:	Date of publication:
DIN 16726	Synthetic Roofing Sheets Synthetic Sealing Sheets (test)	Dec. 1986
DIN 16770, Part 1	Samples of Thermoplastic Resins (Presses) (testing of plastics)	May 1986
DIN 16776	Polyethylene (PE) Resins (plastic resins, classification and labelling)	Dec. 1984
DIN 16887	Testing of Thermoplastics Pipes, Determination of the Behaviour on Long-term Internal Pressure	July 1990
DIN 18200	Surveillance (Quality Surveillance) of Construction Materials, Structural Components and Designs (general principles)	Dec. 1986
prEN 45001	General Criteria for the Operation of Testing Laboratories	October 1988
DIN 50049	Certification of Materials Tests	August 1986
DIN 53353	Determination of Thickness using Mechanical Key Devices (testing of synthetic leather and similar flat materials)	June 1971
DIN 53356	Tear Propagation Test (testing of synthetic leather and similar flat materials)	August 1982
DIN 53361	Determination of Folding Behaviour at Low Temperatures (testing of synthetic leather and similar flat materials)	June 1982
DIN 53377	Determination of Change in Dimensions (testing of plastic foils)	May 1989

Standard No.:	Title:	Date of publication:
DIN 53384	Artificial Weathering or Irradiation in Equipment (UV radiation exposure) (testing of plastics)	April 1989
DIN 53441	Stress Relaxation Test (testing of plastics)	January 1984
DIN 53449	Evaluation of Environmental Stress Cracking, Ball or Pin Impression Method	May 1984
DIN 53455	Tensile Test (testing of plastics)	August 1981
DIN 53479	Determination of Density (testing of plastics and elastomers)	July 1976
DIN 53515	Tear Propagation Test Using the Graves Angle Test with Notch (testing of rubber and elastomers and of plastic foils)	August 1977
DIN 53521	Determination of Performance with respect to Liquids, Vapours and Gases (testing of rubber and elastomers)	Nov. 1987
DIN 53532	Determination of the Permeability of Elastomer Foils to Liquids (testing of rubber and elastomers)	June 1989
DIN 53728, Part 4	Determination of the Viscosity of Solutions: Polyethylenes (PE) and Polypropylenes (PP) in Diluted Solutions (testing of plastics)	March 1975
DIN 53735	Determination of the Melt Index of Thermoplastics (testing of plastics)	Feb. 1988

Standard No.:	Title:	Date of publication:
DIN 53739	Effect of Funghi and Bacteria (visual assessment, change in dimensions or change in physical properties) (testing of plastics)	Nov. 1984
DIN 53861	Out-of-Plane and Burst Test (testing of textiles, concepts)	August 1970
DIN 54307	Punch Penetration Test (testing of textiles)	April 1989
DIN 55350, Part 11	Concepts of Quality Assurance and Statistics: Basic Concepts of Quality Assurance	May 1987
DIN 66050	Suitability for Use (concept)	August 1990

Guideline:	**Title:**	**Date of publication:**
DVS Guideline 2203	Testing of Weld Joints in Thermoplastics.	
Part 1	Test Methods and Requirements	March 1986
Part 2	Tensile Test	July 1985
Part ..	Peeling Test	Draft
DVS Guideline 2212		
Part 3	Testing of Plastics Welders: Testing Group III: Geomembranes Used in Earthworks and Hydraulic Engineering	October 1991
DVS Guideline 2225	Welding of Geomembranes of Polymer Materials in Earthworks and Hydraulic Engineering	
Part 1	Procedure	1991
Part 2	Construction Site Tests	Draft
Part 3	Requirements for Welding Machines and Apparatus	Draft

Guideline:	Title:	Date of publication:
BPG Geomembranes	Construction and Testing Principles for Geomembranes as Lining Elements of Impoundments and Rooms for the Storage of Groundwater Polluting Liquids, German Institute for Construction Technology (Deutsches Institut für Bautechnik, DIBT)	Nov. 1982
GKR Guideline R 1.3.2	HDPE Pressure Pipes, Quality Assurance Society Plastic Pipes (Gütegemeinschaft Kunststoffrohre e. V.)	June 1987

APPENDIX C

ENCLOSURES TO THE CERTIFICATE

Enclosure 1:	Standard values and permitted ranges for quality control and third-party control
Enclosure 2:	Exact identification of the manufacturer together with production sites, and of the installer(s)
Enclosure 3:	Description of the manufacturing process
Enclosure 4:	Manufacturer's statement regarding material (type of resin, proportion of carbon black, use of regrind)
Enclosure 5:	Description of the structure and arrangement of the identification mark
Enclosure 6:	Description of the placing of the identification mark on the geomembrane
Enclosure 7:	Description of quality assurance measures 1) quality control 2) third-party control
Enclosure 8:	Manufacturer's storage and transportation instructions
Enclosure 9:	Description of the roll mark
Enclosure 10:	Guidelines for installation and welding the geomembrane (Extract)
Enclosure 11:	Description of quality assurance measures in the production of the weld seam
Enclosure 12:	Model record for the production of the weld seam (welding machine record)
Enclosure 13:	Model record for the production of the weld seam (hand seam)
Enclosure 14:	Description of the geometry of the weld seam
Enclosure 15:	Model of the weld seam test record (hot wedge)
Enclosure 16:	Model of the weld seam test record (hand seam)
Enclosure 17:	Description of the structure(s) of the geomembrane

APPENDIX D:

STATE CODES AND TESTING INSTITUTES

State codes (Bundesarbeitsblatt 4/91, p. 61):

Baden-Württemberg	01	Lower Saxony	07
Bavaria	02	Nordrhein-Westfalia	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	Thüringen	16

Testing and Third-party Control Institutes for Suitability and Manufacturing Control of the Geomembranes

South German Centre for Plastics (Süddeutsches Kunststoffzentrum)
Institute for the Processing, Application and Testing of Plastics
Herr Glück
Frankfurter Straße 15-17
D-97082 Würzburg

Darmstadt State Materials Testing Institute (Staatliche Materialprüfanstalt Darmstadt)
Plastics Division
Herr Heimer
Grafenstr. 2
D-64283 Darmstadt

B Büttgenbach, I Jakob and Dipl-Ing R Tatzky-Gerth of the Landfill Engineering Laboratory also participated in drafting the guidelines. When the certification work began in 1988, a large number of suggestions were submitted by the Lower Saxony Ministry of the Environment (Niedersächsisches Umweltministerium), the Federal Environmental Agency (Umweltbundesamt), the TI Hazardous Waste "Landfill" Working Group, the Working Group on "Ground Water Protection Geomembranes" and the DVS Study Team "Geomembranes", and these have also been included in these guidelines.

English text: Hilary Gurney, Outwood Translations, Horsforth, Leeds, England.
Revised by Mr Nigel Pye, Pollution Control Manager in Kent Waste Regulation Authority, Maidstone, England.