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THERMOPLASTIC POLYOLEFINS

Long-term characteristics of sealing sheets made from ECB

Technical Paper

Leopold Glück [1)]

Long-term characteristics of sealing sheets made from Ethylene Copolymer Bitumen (ECB) used for construction sealing and in geotechnics (reservoirs, storage lakes, canals, tunnels, etc.)

For some 40 years plastic sealing sheets made from ECB (Lucobit 1210) are used in civil engineering to efficiently seal off flat roofs, patios, tunnels, dams, ponds, reservoirs, landfills and many other constructions.

ECB sealing sheets are applicable under every common operational condition. Even in long-term applications they are sufficiently resistant to general constructional e.g. mechanical, thermic, biological and chemical strains

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1) General

To apply sealing sheets in constructions that have to guarantee a long life-span, one has to know about their long-term characteristics. Therefore it is necessary for the constructor to gain information about these long-term characteristics. Only then will he have the guarantee that the required characteristics of a material will remain reliable throughout the construction's serviceable life. Sealing sheets are oftentimes applied in places that are hard or sometimes even impossible to reach, which makes it difficult if not impossible to replace them.

This technical paper deals with the long-term characteristics of sealing sheets made from ethylene copolymer bitumen (ECB), used for the sealing of reservoirs, water storage dams, canals, tunnels and buildings. The applications are for sealings against ground- and mountain water. The sealing of landfills or materials incompatible with water is not examined.

2) The new European Standard for sealing sheets

The subject of "moisture protection" plays an important part regarding the European Construction Product Directive (CPD) with its corresponding basic documents and its implementation into German Law by means of the Directive of Building Materials.

It determines the basic requirement about health and hygiene i.e. the moisture protection of a building, suitable for housing people. The usability of materials according to the basic requirements of buildings is defined based on European technical specifications whose definition has been mandated by the European Commission.

These are primarily Harmonized European Norms (hEN) but also European Technical Approvals (ETA) which are dealt with at the European Committee for Standardization (CEN) or the European Organization for Technical Approvals (EOTA).

The proven conformity of a product with technical specifications is indicated by means of applying the CE-Mark onto the product or its accompanying documents.

According to European Standards or European Technical Approvals sealing products have to be suitable for the production of sealings that meet each member state's demands for moisture protection. That is to say, the technical specifications have to apply to those characteristics for which there are legal requirements made by the member state. This is to be assured by the definition of the commission's mandates to the CEN and EOTA.

Based on these mandates a series of European product standards and their according testing standards has been developed within the TC 254 for Roof- and Construction Sealing as well as the TC 189 for geosynthetic sealing sheets. In the future, sealing products under present German Product Norms (DIN 16729, DIN 16730, DIN 16731, DIN 16734, DIN 16735, DIN 16736, DIN 16737, DIN 16935, DIN 16937 and DIN 16938) carrying the "Ü-Sign" – the German Mark of Conformity - will be replaced by products according to hEN carrying the CE-Mark.

Technical approvals for sealing products based on mandated guidelines (ETAG) or so called CUAP-procedures (Common Understanding of Assessment Procedures) will also be given by the EOTA. These products as well will receive the CE-Mark and the permission to be introduced to the market.

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Harmonized European Norms (hEN) for sealing sheets

The CEN TC 254 "Flexible sheets for waterproofing" has so far compiled four European Norms for sealing sheets in construction sealing, made from elastomers and plastics:

- **EN 13956** "Plastic and rubber sheets for roof waterproofing"
  Transitional period: July 1, 2006 – July 1, 2008
- **EN 13967** "Plastic and rubber damp proof sheets including plastic and rubber basement tanking sheets"
  Transitional period: October 1, 2005 – October 1, 2006
- **EN 13984** "Plastic and rubber vapor control layers"
  Transitional period: September 1, 2005 – September 1, 2006
- **EN 14909** "Plastic and rubber damp proof courses"
  Transitional period: February 1, 2007 – February 1, 2008

The CEN TC 189 "Geosynthetics" has so far compiled six European Norms for so-called "Geosynthetic Sealing barriers" (GBR), which include three product groups:

- Polymeric Geosynthetic barriers (GBR-P)
- Bituminous geosynthetic barriers (GBR-B)
- Clay geosynthetic barriers (GBR-C)

The following application norms for geosynthetic barriers have been defined:

- **EN 13361** "Geosynthetic barriers – Characteristics required for use in the construction of reservoirs and dams"
  Transitional period: September 1, 2005 – September 1, 2006
- **EN 13362** "Geosynthetic barriers – Characteristics required for use in the construction of canals"
  Transitional period: February 1, 2006 – February 1, 2007
- **EN 13491** "Geosynthetic barriers – Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures"
  Transitional period: September 1, 2005 – September 1, 2006
- **EN 13492** "Geosynthetic barriers – Characteristics required for use in the construction of liquid waste disposal sites, transfer stations or secondary containment"
  Transitional period: September 1, 2005 – September 1, 2006
- **EN 13493** "Geosynthetic barriers – Characteristics required for use in the construction of solid waste storage and dis posal sites"
  Transitional period: March 1, 2006 – March 1, 2007
- **prEN 15382** "Geosynthetic barriers – Characteristics required for use in transportation infrastructure", Draft 2005

The start of the transitional period determines the date as of which a sealing sheet with a CE-Mark shall be introduced to the market. During the 12-month transitional period products may be distributed with the corresponding national mark, i.e. the German "Ü-Mark". After the transitional period only products that carry the CE-Mark are allowed on the market.

The products have to prove their conformity i.e. their compliance with the mandated parts of the norms (Appendix ZA), according to the Attestation of Conformity procedure determined in the mandate. With regards to their function as sealing sheets the system 2+ has been determined for most sealing products. Here, the manufacturer inspects the products' characteristics in an initial control conducted by him personally and the ongoing factory production control. A third instance (Certification Center) partakes in the certification of the factory control and its ongoing monitoring.

The manufacturer has to draw up a conformity declaration stating that all tasks were performed appropriately. In applying the CE-Mark onto the product and its accompanying documents the manufacturer eventually certifies the conformity of the product with the Harmonized European Norm.

Details about the application of a CE-Mark and additional data are described in the norms' appendix ZA. Subsequently, the product not only has to carry the CE-Mark as well as the

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number of the certification center but also information about its essential characteristics. This information has to be repeated in the accompanying documents and supplemented with further information about the products' proven characteristics. Those characteristics, for which no statement is made, need to be labeled "no performance determined" (NPD).

During the development of these norms the possible introduction of limit values or performance classes for consistent definitions of the proficiency level could not be agreed upon. This would have made the use of sealing products in the member states considerably easier.

Therefore, there are no requirements made for most characteristics. The manufacturer merely has to make statistical statements about the limit or average values of his production data.

The broad definition of the norms permits practically every sealing product – irrespective of its material composition and characteristics – to be classified under one of the product norms, labeled with a CE-Mark and introduced to the European Market.

The use of sealing products according to Harmonized European Norms

Based on the Directive of Building Materials and with the help of Harmonized Norms the mere usability of a product is determined in order to label it with a CE-Mark and introduce it to the markets of the member states. However, the member states are entitled to their national security and safety levels for constructions and construction parts (e.g. sealings) remaining intact, when availing themselves of products that were labeled according to European norms. To do so they need sealing products with characteristics that guarantee that the sealing complies with national guidelines. Therefore the member states have the right to define additional guidelines for the use of products standardized according to European norms.

In Germany, so-called "application norms" are supposed to close the gap between sealing products standardized according to European norms and their use according to national construction norms. These application norms define the performance profile, which, according to Harmonized European Norms, sealing products have to comply with if they are to be considered suitable under the safety and security levels according to the construction norms DIN 18195 or DIN 18531. The performance profiles of sealing products according to the present German product norms provide the basis for this assessment.

The application norms for sealing products have been defined by the DIN-Institute:

- **DIN V 20000-201** "Adaption standard for flexible sheets for waterproofing according to European standards for the use of waterproofing of roofs."
- **DIN V 20000-202** "Adaption standard for flexible sheets for waterproofing according to European standards for the use of waterproofing of constructions."

In Germany, sealing products that do not meet these requirements are not allowed to be used for the type of sealings stated above, even if they carry the CE-Mark and have been properly introduced to the market, unless the manufacturer provides a special certificate of applicability.

Many European countries have national applicability norms, guidelines and approvals for geosynthetic barriers, especially for disposal sites (BAM approval in Germany, ÖNORM S 2073 in Austria, KIWA guideline BRL K538 in The Netherlands, ASQUAL-approval in France) and for tunnel constructions (ZTV-

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ING [24], Rili 853 [25] and EAG-EDT [26] in Germany, SIA V 280 [22] in Switzerland, issue 365 of "Straßenforschung" in Austria).

Consequently, the CE-Mark constitutes a kind of "passport" to introduce sealing sheets to EU-Markets but is no "driving license" guaranteeing the possible use of sealing sheets because many countries have additional national regulations for its applicability.

3) Introduction to the deterioration process

During the material's processing and use all of its characteristics are subject to changes. These changes are commonly specified by the term "deterioration", its definition for plastics being "The entity of a material's irreversible chemical and physical processes over the course of time."

Deterioration can have the following causes:

a) Thermodynamic, instable state of the material (interior causes of deterioration) and/or
b) Chemical and physical exposure by the environment (exterior causes of deterioration)

The processes causing a material's deterioration are divided into:

a) Chemical deterioration processes (changes in the composition, the size and structure of the material's molecules) and
b) Physical deterioration processes (e.g. changes in the microstructure, the shape and structure and the physical characteristics of the material)

The DIN 50035-2: 1989-04 "Polymer materials" states the following causes for deterioration:

I. Interior causes of deterioration:
- incomplete polycondensation, polymerization or polyaddition
- residual strains and orientations
- limited miscibility of single components (e.g. plasticizers or emollient components) with the highly polymeric basic material

II. Exterior causes of deterioration:
- thermic strain
- chemical strain
- mechanical strain
- strain from radiation (ionized radiation)
- biological strain
- atmospheric strain (photochemical deterioration)

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The following Chart 1 gives an outline of the impacts that may cause the deterioration of a material, the mechanisms that are stimulated (causes) and how they can be measured.

Impact	Effect	Measurement
	Mechanical deterioration	
Static	Creep	Expansion, Failure mode
Dynamic	Fatigue	Stress reversal, Stability
Wear	Abrasion	Dimension Surface
	Chemical deterioration	
Heat	Chain scission	Molecular weight, Viscosity/Stability
	Depolymerization	
Oxidation	Chain expansion Chain aborization	Rigidity/ Viscosity Oxidation Induction Time (OIT)
Hydrolysis	Chain scission	Molecular weight, Viscosity/Stability
Radiation/Light	Cross-linking Chain scission	Molecular weight Rigidity/Viscosity/Stability, Optics
Medium	Chain scission	Molecular weight, Viscosity/Stability
	Cross-linking	Molecular weight, Viscosity/Stability
	Physical deterioration	
Heat	Molecular flexibility Expansion	Viscosity/Stability Dimension
Medium	Expanding Dissolving	Mechanics Hardness
	Formation of stress cracks	Creep strength

Chart 1: Deterioration impacts and their effects on plastic materials

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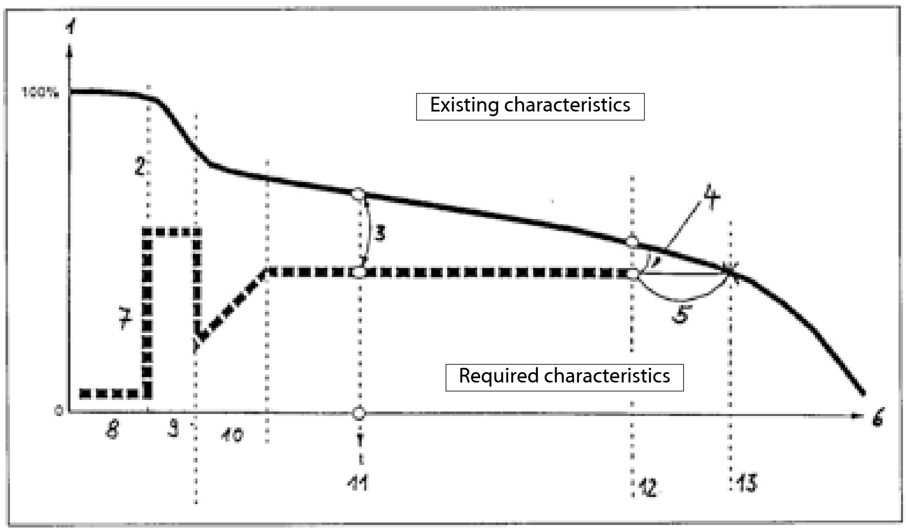
4) Durability

Construction sealings are nonrenewable and there are only few conditions under which it is economical to repair them. Therefore, the sealing has to be constructed to last over the construction's complete lifecycle.

To assess the functionality (durability) of sealing sheets it is necessary to examine the time-related impacts of the functional characteristics. The type of polymers used, the structure of the sheets (homogeneous, reinforced by a geomembrane or other material…), the manufacturing method, the installation strain as well as the physical and chemical strains during use are the essential parameters, having an impact on the durability of a sealing.

The schematic interrelations are apparent in the following illustration:



1 Functional characteristic
2 Material behavior
3 Safety
4 Material safety at the end of the prospective usability period
5 Safety during time before breaking
6 Duration
7 Requirements
8 Storage; Processing/Handling
9 Installation
10 Strain
11 Physical and chemical deterioration
12 Designated service life
13 End of lifecycle: functional deficiency

Chart 2: Typical course of existing and required values for time-related functional characteristics [2]

The upper curve represents the change within a relevant feature caused by those strains the construction has to bear from the time of its production until the end of its functionality. The requirements a construction has to meet depending on the existing strains are illustrated in the lower curve. The user determines the designated service life on the time axis.

The guideline F of the Directive of Building materials 89/106/EWG "Durability and the Directive of Building materials" stipulates the projected serviceable life of constructions and products [1]. According to this, the projected serviceable life of a construction under the category "long" shall be 100 years; the projected serviceable life of the building material shall also be 100 years unless it is repairable or economically replaceable:

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Projected serviceable life of constructions (years)		Projected serviceable life of construction materials (years)		
Category	Years	Category		
		Repairable or easy to replace	Less easy to repair or replace	Serviceable life of the construction[1)]
Short	10	10	10	10
Medium	25	10	25	25
Normal	50	10	25	50
Long	100	10	25	100

1) non-repairable or economically replaceable products.

Chart 3: Example of projected serviceable life of constructions and products (by EOTA) [1]

By the end of the projected serviceable life a certain safety has to be assured so as to estimate the failure for a time, that by far exceeds the projected serviceable life. The ratio between the projected existing characteristics and the projected required characteristics constitutes the total safety factor of the construction part. It can also be conveyed as the time until failure, if the building materials were to stay in use after the end of the projected serviceable life.

5) Basic information about ethylene copolymer bitumen (ECB)

Ethylene copolymer bitumen (ECB) is a thermoplastic material based on ethylene polymers and selected distilled bitumen. The material was already developed in the 1960ies by the BASF AG and introduced to the market under its trade name "Lucobit" (deriving from "Ludwigshafen Copolymerisat und Bitumen). The trial product "Lucobit KR 1210" was introduced at the "K67" exhibition, the basic patent was granted in 1973.

In this composite, the plastic component (n-butyl acrylate) constitutes the supporting structure, with interspaces for the drop-shaped emplacement of the bitumen as a plasticizing element. The bitumen works as a plasticizer and absorber of ultraviolet light. The plastic structure guarantees the durability, elasticity, tensile strength and flexibility required for all sealing materials even at temperatures below the freezing point as well as the stability at higher temperatures. The standard material Lucobit 1210 becomes brittle at temperatures below -30 °C and softens at temperatures above 80 °C [3].

Newer Lucobit types (Lucobit 1218 and 1233) have a higher heat deflection temperature compared to Lucobit 1210 i.e. higher rigidity at high temperatures and an improved cold flexibility.

The determination of dynamic-mechanic characteristics e.g. in an oscillation experiment enables the characterization of mechanical properties against temperature.

The rigidity curve of Lucobit 1210, 1218 and 1233 against temperature is shown in Chart 4, which demonstrates the

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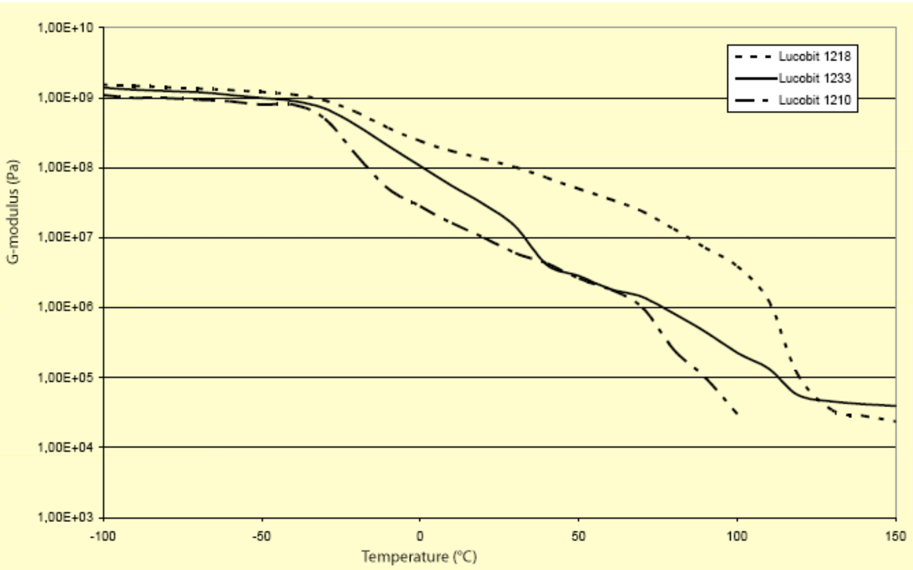
temperature-related course of the shear modulus G and the logarithmic decrement of the attenuation Λ.

Different states can be determined from the curve progression:

- High modulus values and low attenuation indicate the frozen state at low temperatures
- Temperature ranges, in which the modulus values strongly decrease with the temperatures and the attenuation values reach maxima indicate the softening ranges (glass transition)
- Low modulus values and low attenuation values indicate the range up to the melting point

Thus, the shear modulus works as a measure for a material's rigidity while the logarithmic decrement works as a measure for its interior attenuation.



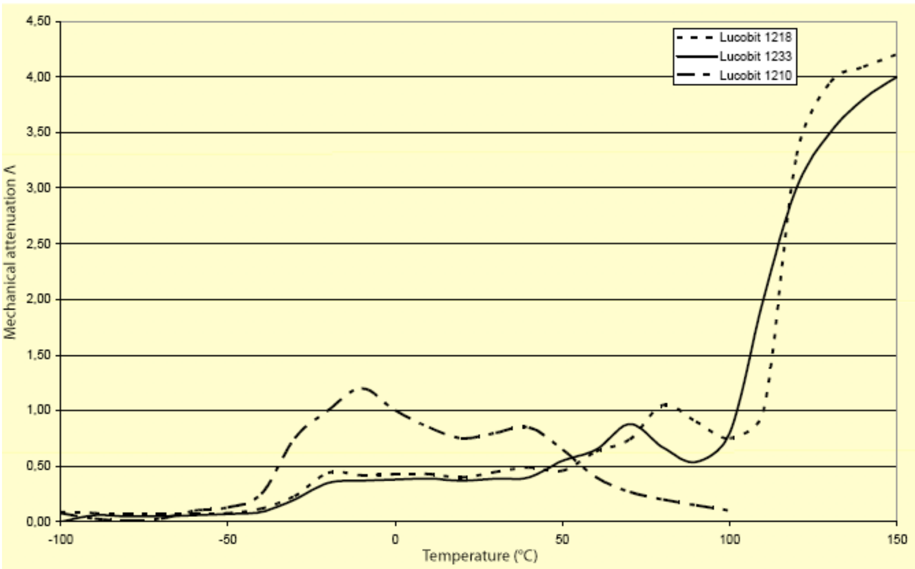


Chart 4: Temperature dependency of the shear modulus G and the logarithmic decrement of the attenuation, for the Lucobit types 1210, 1218 and 1233.

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6) Plastic sealing sheets from ethylene copolymer bitumen (ECB)

ECB is sold as powdered granulate and is thermoplastically processed in an extrusion unit with a slot die, as is usual in the processing of plastic materials [4]. The sheets are cooled down and flattened by subsequently arranged smoothing rolls. Thanks to the use of embossing rollers the sheets' surfaces can be grained or otherwise structured. In 1968 the first 2.5 mm-thick sealing sheet was manufactured.

Plastic sealing sheets made from ECB were first standardized in 1976 under the DIN 16732 Standard Parts 1 and 2, and later in 1984 under the DIN 16729 [11] Standard.

The thickness, width and length of the homogeneous sheets, which are either furnished with a glass fiber, fabric insert and/or with laminations can be adjusted according to the production program and the requirements made.

7) Strains of sealing sheets in construction sealings

The material-specific requirements are recorded in the relevant Regulations (SIA V 280 [22], ZTV-ING [24], Rili 853 [25], Tunnel-EAT [26], DVWK Guideline [23] etc.). These requirements primarily serve the material's description as well as the compliance with any quality criteria within the production control.

Moreover, the sheets have to be permanently resistant against ground- and mountain water as well as other exterior impacts and must not lose their protective properties (impermeability) when exposed to the usual movements of the construction caused by shrinking, thermal fluctuation and settling. In this context, "impermeability" is defined as watertightness.

Therefore, strains do occur during the installation, the pouring of the concrete and the usage and may differ from construction to construction. Thus, the respective requirements as well as their control and supervision have to be defined according to the project.

The impermeability may be affected by [21]:

- Defective caulking of the sheets or connection of the sheets to the expansion strips, permeations etc.
- Mechanical strain before and during the pouring of the concrete
- Mechanical strain after the pouring of the concrete as well as during the operating stage (tensile load caused by adapting the sealing to an uneven construction part during the pouring of the concrete, compressive load caused by the permanent load of the building, mountains etc.)
- Thermic strain
- Chemical strain
- Biological strain (microorganisms, shoots and roots)

7.1) Mechanical environmental strains

Mechanical impacts occur during the installation phase (transportation and storage, installing the components of the sealing system etc.) as well as during operation (uneven installation, hydraulic strain caused by surface- and groundwater, mass of the applied soil, dead load of constructional units etc.). The mechanical impacts lead to tensile and/or compressive loads.

The behavior at uniaxial tensile load is calculated in standardized tensile tests. The tension-expansion diagrams as well as the specific values (tension, expansion) provide information about the general deformation behavior and the failure of the material (Chart 5).

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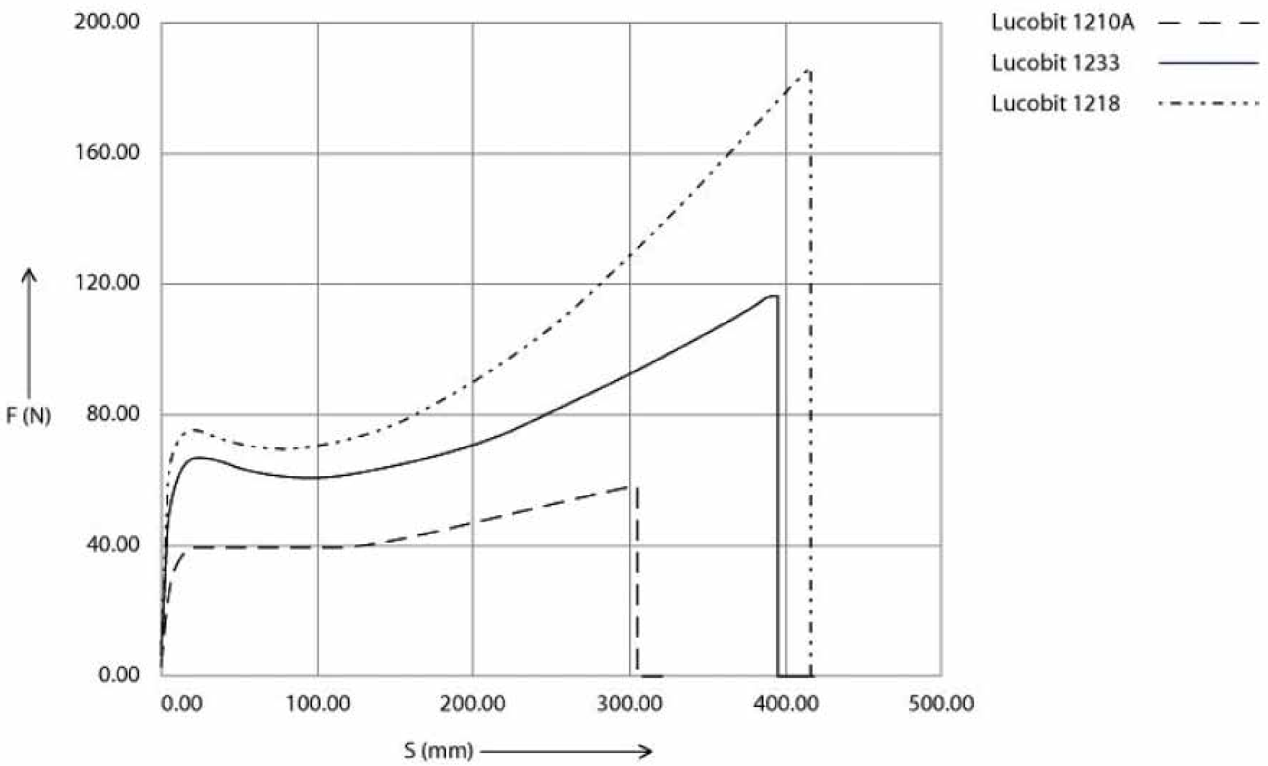

Chart 5: Behavior in tensile test at uniaxial strain of sealing sheet from ECB at standard atmosphere 23/50-2

A more comprehensive study of the behavior under tensile- and compression load is only possible if the properties of rigidity and deformation at different testing conditions (speed, temperature, pre-treatment) are determined.

Permanent strains appear in the form of constant tensile deformation (adaption of the sheet to the voids) or constant compressive stress (rock pressure, hydrostatic pressure). Due to the distinct relaxation properties of plastic materials and depending on the type of polymer, stresses are reduced at different rates. However, soft elastic plastics are not suitable for the permanent bearing pressure of tensile loads.

Especially for processing reasons (handling, welding properties) but also from an application point of view, it is preferable to use sheets with a certain rigidity (flexibility).

By and by the relevant Regulations are including the respective assessment criteria and requirements in their revisions ([24] and [26]). Regarding the flexibility, sheets with an E-modulus value of below 80 N/mm^2 are generally considered suitable for tunnel constructions. Chart 6 shows the rigidity of standard sealing sheets. The rigidity of sealings sheets based on polyethylene and ECB can be varied through adequate modifications.

In case of the ECB, the rigidity is defined through the drop shaped emplacement of varying amounts of bitumen in the interspaces of the supporting ethylene copolymer n-butyl acrylate structure.

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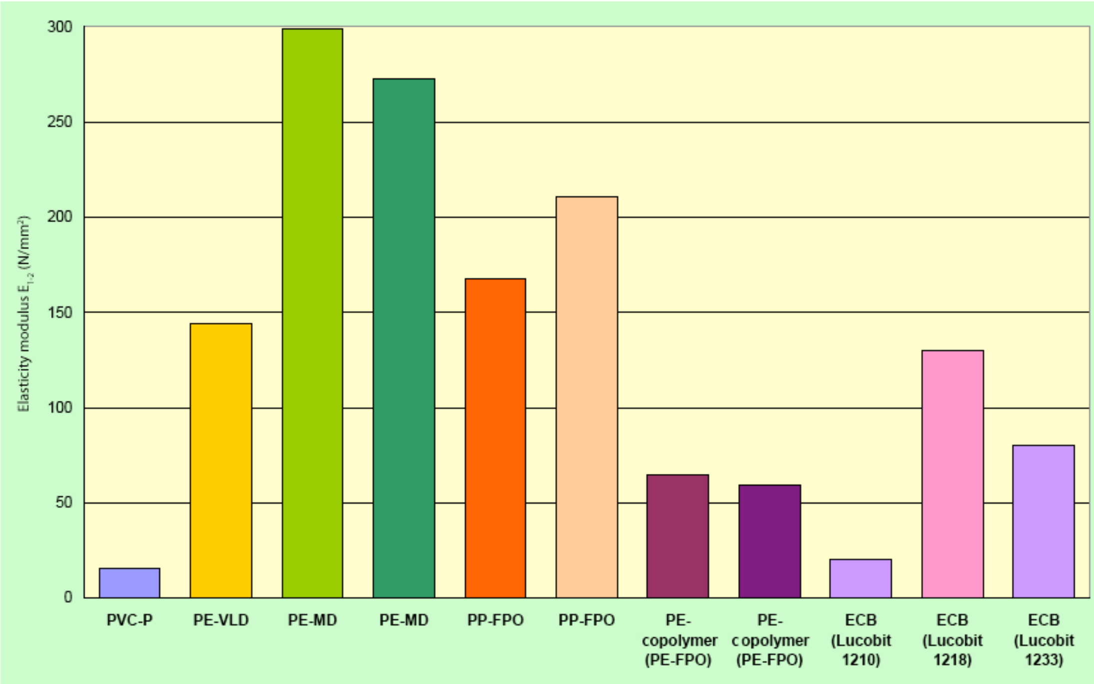

Chart 6: Elasticity modulus (E1-2-modulus) of standard sealing sheets at standard atmosphere 23/50-2 [21]

The creep behavior of ECB sealing sheets under compressive load is similar to the behavior under tensile load. Even under low permanent compressive load there is a short (approx. 20 days) period of creeping [9]. Authoritative for the pressure behavior of laminar Lucobit bodies is the compression modulus that is given for the three fundamental states i.e.:

- Without sideways obstruction (compression modulus K_0)
- Uniaxial total obstruction (compression modulus K_1)
- Biaxial total obstruction (compression modulus K_2)

by means of the elasticity modulus E (pressure elasticity modulus) and the Poisson's ratio μ.
This means that the compression is reduced with increasing obstruction. In the case of a dual total sideways obstruction, compressive loads of 10 N/mm are permissible if the creeping effect is irrelevant [9].

The behavior under permanent compressive stress can be determined in a long-term compressive test. The chronological sequence of the compression (gauge reduction) depending on the permanent compressive stress is shown in Chart 7 using the example of Lucobit 1210 [9]. During the subsequent release the Lucobit boards have almost completely reshaped within half an hour. Similar behavior can be expected from Lucobit 1218 and Lucobit 1233

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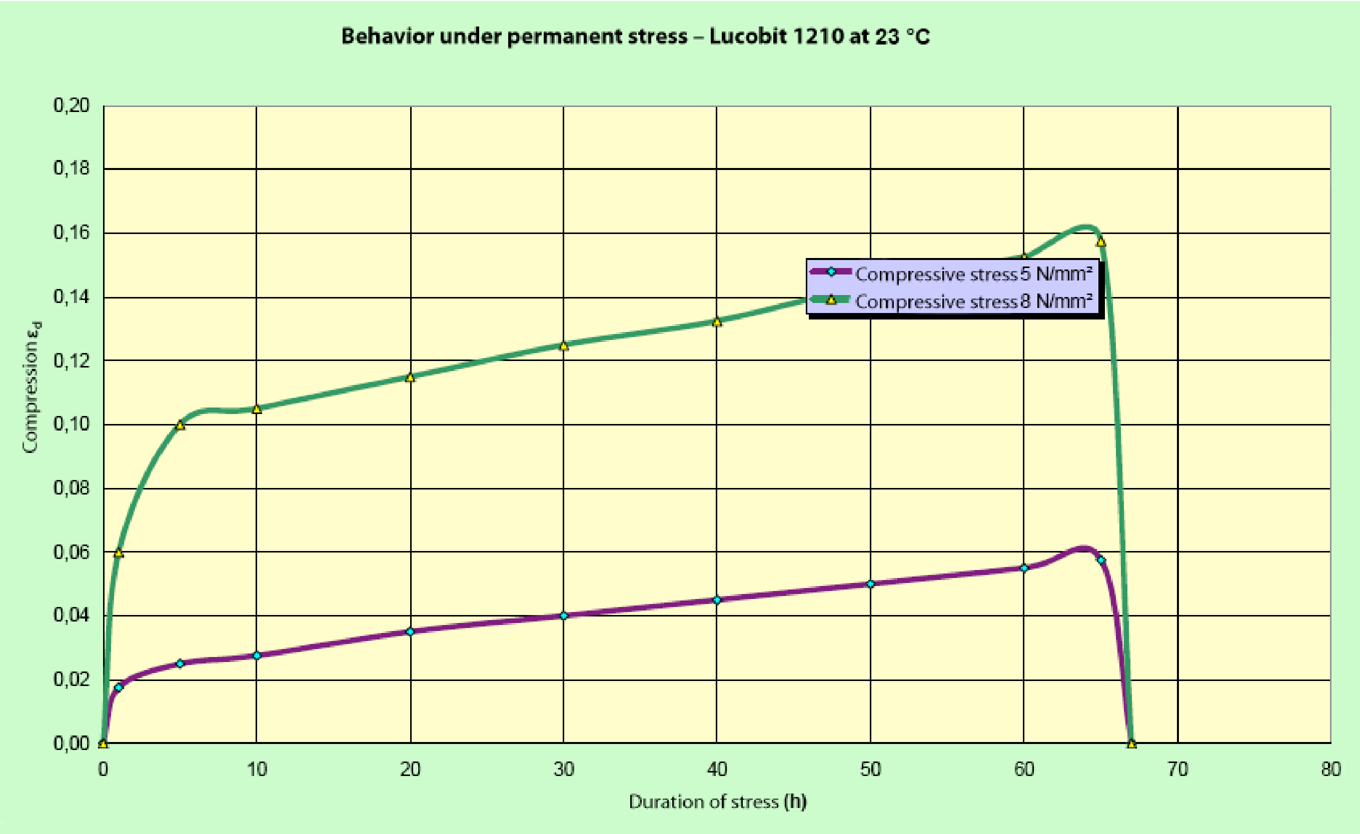

Chart 7: Behavior under permanent stress – Lucobit 1210 [9]

7.2) Thermic strains

Thermic strains may result from rock pressure. Heat has a physical as well as a chemical impact on macromolecular materials. Physical impacts result in reversible changes of properties (softening under rising temperatures); chemical impacts lead to irreversible changes in usage properties.

Polyolefins are highly resistant against thermic decomposing. In the presence of oxygen, polyolefins are decomposed in a thermic-oxidative way. The deterioration process is accelerated with rising temperatures. Experts avail themselves of this method to extrapolate for longer durations of stress using condensed thermic deterioration at high temperatures.

Besides measuring the melt-index and insoluble elements, measuring the deformation characteristics under tensile load is an especially reliable chemical-physical method to examine the deterioration process. After 15 month of storage at 70 °C the Lucobit 1210 sealing sheets show no change in their tensile strength and elongation at break [7], therefore there are no visible deterioration effects.

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7.3) Chemical impacts

Plastic sealing sheets are generally installed in natural soils and are exposed to natural groundwater. Normal uncontaminated soils usually do not contain chemicals that could be critical for synthetic sealing sheets. This is true as long as the ph-value of the soil remains between 4 and 9. In acidic and highly alkaline soils however, an exact analysis is necessary. The chemical resistance of sealing sheets has to be examined for cases in which the exposure to chemicals cannot be exempt:

Application Area	Possible chemical impacts
Road construction	Fuels, road salt
Railroads	Pesticides
Tunnels	Mountain- and groundwater (increased amount of sodium, magnesium, calcium, chloride, sulfate and carbon dioxide)
Constructions	Fresh concrete

Chart 8: Examples of chemical impacts depending on the application area [17].

Chart 9 lists the processes that are triggered by the impact of chemicals on a polymer product. The durability of a polymer material against a chemical impact depends not only on the polymer in use but also on the molar mass, the cross linking, the type of side chains, the crystallinity and the density of the material. This is why the required or estimated durability is already influenced strongly by the choice of manufacturing.

Physical effects		Chemical reaction
Reversible	Irreversible	
• Moisture expansion • Softening	• Dissolving • Erosion of additives • Chemically induced relaxation • Environmental stress cracking (ESCR)	• Oxidization/reduction • Ozonolysis • Hydrolysis • Other chemical reaction

Chart 9: Processes triggered by the impact of chemical substances

To test the chemical durability the contact with a liquid chemical substance like acids or alkalis is simulated. To achieve a faster reaction to the chemical impacts the temperature as well as the concentration of chemicals is increased. For the test the samples are stored inside the test-media over longer periods and in certain intervals any changes of the weight or the mechanical properties under tensile load are determined.

The chemical durability of Lucobit is generally pre-set by the components polyethylene and bitumen. The ethylene copolymer is basically insoluble at temperatures below 60 °C. It shows only little signs of surface swelling under the influence of alcohols, organic acids, ester, ketones and similar substances. However, aliphatic and aromatic hydrocarbons and their halogen derivatives cause substantial moisture expansion and softening of the material.

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PE-sheets belong to those materials that are highly resistant against chemical impacts. They are resistant against water, inorganic salts, alkalis and acids and are only affected by strong oxidants, which definitely do not occur in the sealing of tunnels and constructions. Due to their nonpolar properties the water absorption is very low i.e. below 0.05 %.

Over a period of five years, the Moor Research Center at the Bavarian State Research Center for Natural Resources, Plant Production and Plant Protection in Bernau stored sample products made from Lucobit in a moor, which is rich in humic acids. The ph-value of the soil was 4.0, 3.2 in flowing waters. The Lucobit 1210 has remained practically unaltered [7] (see Chart 10); similar behavior can be expected from Lucobit 1218 and 1233.

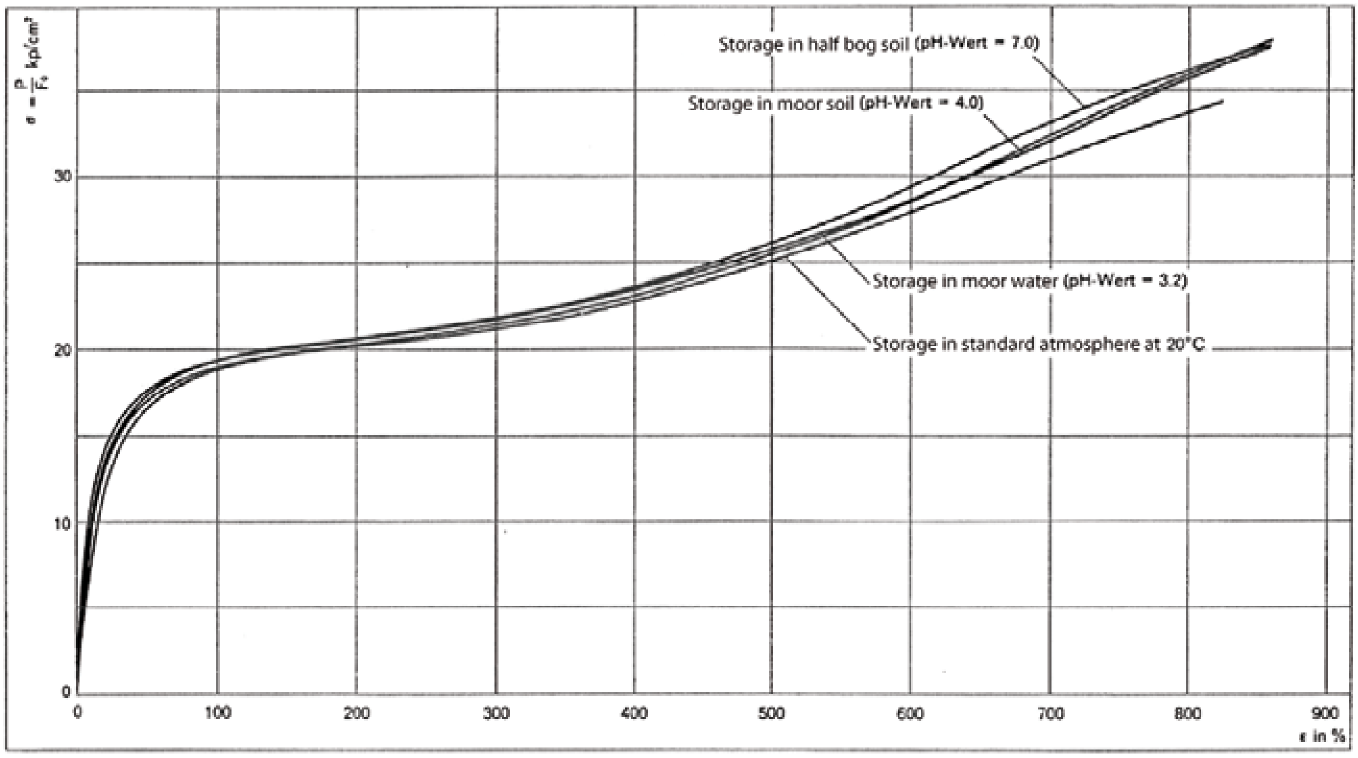

Chart 10: Stress/Expansion diagram of Lucobit 1210 after three years of storage in highly acidic soils [7]

Chart 11 shows the change of mass after water-storage at 50 °C as well as after subsequent drying of sealing sheets made from different materials. Sealing sheets manufactured on polyethylene bases show no signs of quelling or extraction.

After 10 months of long-term storage of Lucobit 1210 in 20 °C water as well as 2.500 hours of alternating storage (16 hours of periodic deterioration caused by UV-rays and 8 hours of water storage) the material showed no changes in its mechanical properties whatsoever [7] and may therefore be considered uncritical.

On the other hand sealing sheets made from PVC-P expand relatively strong – depending on their components and the type of softener – and show considerable weight losses after drying. This is basically a reaction from the softener leading to

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a gradual stiffening of the material. The considerable weight increase (more than 10 mass-%) of the PVC-P-BV (PVC with polymer softener) is striking. This sealing sheet does show the highest loss in weight after drying.

The extraction speed increases considerably if the PVC-sealing sheets are stored in flowing waters [20], which means that an increase of the stiffness can be expected after a considerably shorter period of time. After 12 years there remained efficient flexibility (softness) even though the loss of mass after drying was up to 9 %.

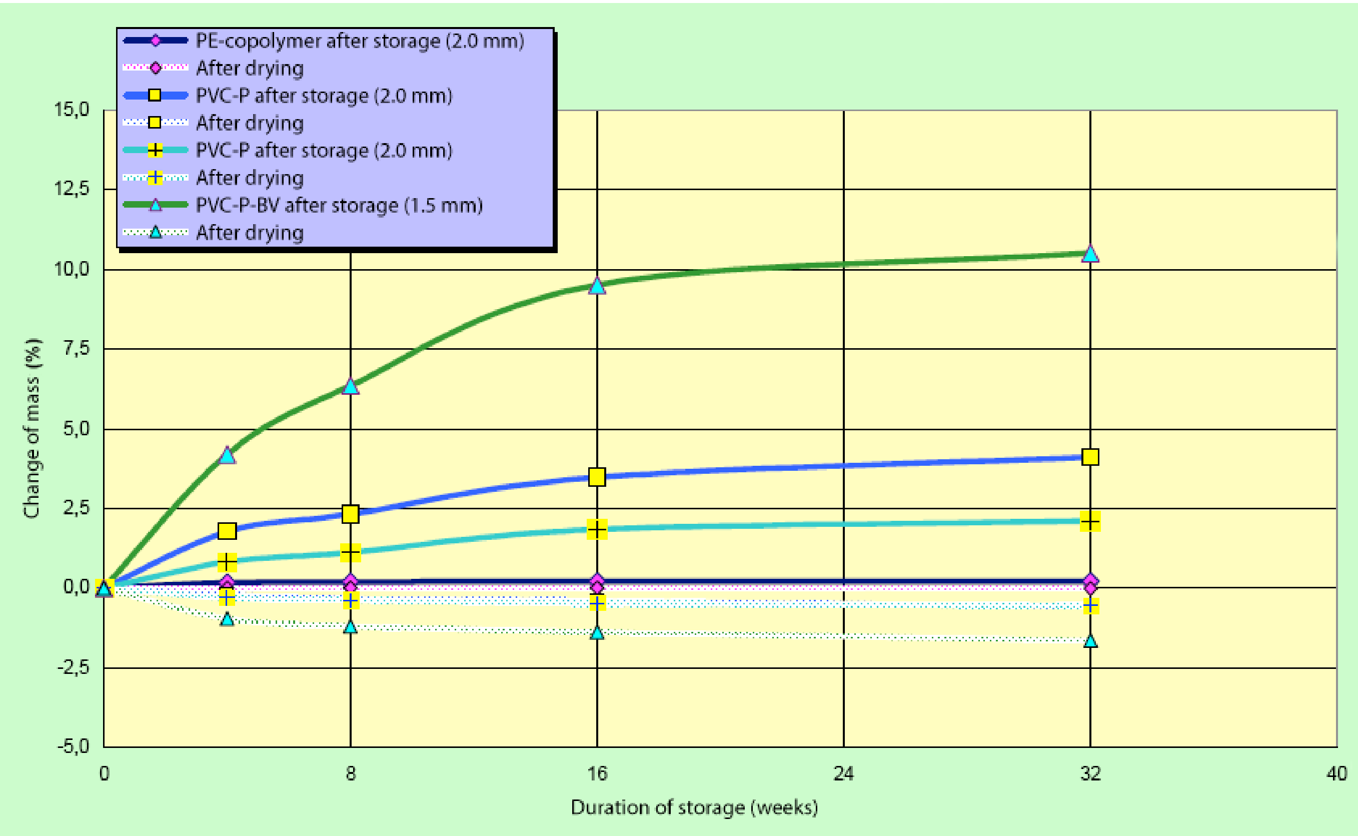

Chart 11: Change of mass after water storage at 50 °C according to SIA V280

A hydrolysis conducted under the impact of water is only of importance to plastics that were manufactured under polycondensation reactions (polyamides, polyester). However, polyolefins like PE, PP and PVC, which were manufactured by polymerization reactions (with the respective softener models) are resistant to hydrolysis.

The European Standard EN 13967, Appendix C.1 describes a test procedure to determine the durability of sealing sheets in alkaline environments. The procedure is to be applied for sealing sheets that shall be installed as moisture barriers or directly on the ground. Over a period of 24 weeks the test pieces are brought into contact with a moist concrete surface and exposed to a permanent load at a constant temperature

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of 90 °C. Afterwards, the mechanical properties are compared to those of a material sample that has not been under strain.

After the deterioration process sealing sheets made from Lucobit 1233 showed no signs of damages or wear e.g. holes, cracks or staining. The change of the elongation at break was 25 %, which is by far below the allowed change of 50 % compared to the original value.

8) Life-span of sealing sheets

The long-term characteristics of sealing sheets i.e. the connection between strain and deterioration can be determined in various ways:

- The systematic quantitative and qualitative analyses of previous practical experiences (case histories)
- Application oriented long-term accelerated testing (durability tests)
- Qualitative and quantitative observations of models based on the exact knowledge of the material's properties and known deterioration mechanisms (modeling)

By means of modeling even the results of long-term accelerated testing have to be extrapolated with regards to application conditions. The increased concentration of impacting media, the increase of mechanical strain and most notably increasing temperatures accelerate the deterioration process.

Comprehensive studies regarding long-term characteristics were executed at polyethylene pipes. In a creep rupture test closed-off pipe sections are stored in water quenches with differing temperatures and exposed to constant internal pressure. After a certain period of time, the complex strain of the multiaxial stress condition, the impact of the medium (generally water) and high temperatures lead to cracks in the pipe. If the test strains are double-logarithmically applied extending the respective stress rupture life, a typical curve progression for each testing temperature emerges with different branches that are each characteristic of the different rupture modulus' and subsequently the signs of aging (Chart 12).

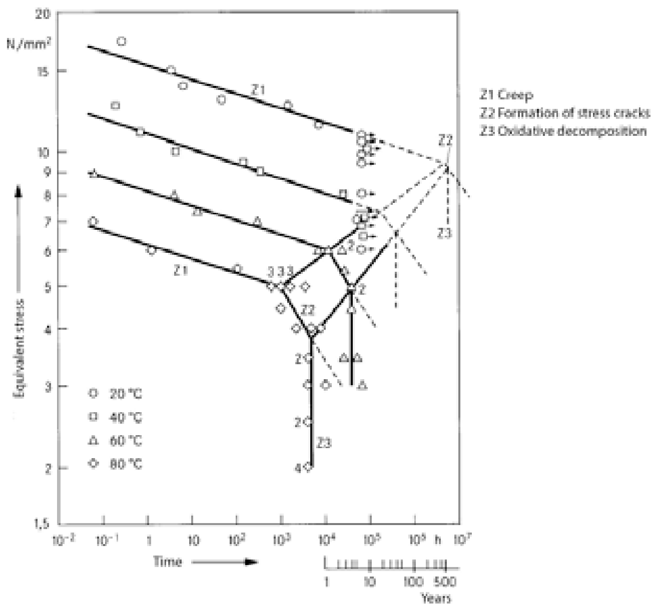

Chart 12: Rupture strength of pipes made from polyethylene (Hostalen GM 5010 T2)

The first branch of the test curve, which is in most cases not too steep, is defined by ductile failure. The first bend of the curve shows the transition to the failure caused by the formation of stress cracks. The second branch indicates the impact of these aging effects. Finally, the third bend is caused by the incipient oxidative decomposition. Due to the oxidative embrittlement of the material even light stresses lead to failure. Therefore the third branch is virtually vertical.
If the time-related bends of the curve at varying temperatures are entered in an Arrhenius diagram, the resulting straight line can be extrapolated towards lower temperatures. For typical application temperatures (10 °C to 20 °C), a life-span of considerably over 100 years can be expected i.e.

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the oxidation reactions do not set in before the consumption of the stabilizer package after this long period of time. In this state there are no signs of change regarding the deformation properties. It would take further centuries until the deformation properties (elongation at break) have decreased to a level where sealing properties are no longer guaranteed.

In general it is expected that thermo – and photooxidative deterioration effects of flexible polyolefins (FPO) and ethylene copolymers such as Lucobit 1210, 1218 and 1233 are virtually equal to those of standard polyolefins.

9) Fields of application

Sealing sheets made from Lucobit 1210 have secured a wide range of application fields within the construction sector. In addition to applications in building constructions (flat roofs, patios), Lucobit sealing sheets are used in underground engineering e.g. parking decks, parking garages, tunnels and tunnel constructions, water- and settling tanks, ponds and reservoirs, canals and embankment dams, landfills etc. BASF documented the various technical trial tests in numerous reports including all necessary project information, most notably the following applied reports [13] and publications:

- 177 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Construction L 950) 1973
- 187 “Sheets from Lucobit 1210 designed for reconstruction of a railroad embankment” (Stroit), 1979
- 183 “Covers from Lucobit 1210 designed for track construction (outside construction L 613), 1973
- 184 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Ludwigshafen- Friesenheim), 1973
- 195 “Sheets from Lucobit 1210 designed for reconstruction of a railroad embankment” (Nearby Braunschweig), 1973
- 196 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Construction D 102), 1973
- 197 “Sheets from Lucobit 1210 designed for sealing of flat roofs” (Construction Z 23), 1973
- 198 “Covers from Lucobit 1210 designed for sealing of earthworks” (Nearby construction K 356), 1970
- 201 “Covers from Lucobit 1210 designed for lining of sewage detention pond” (Nearby Construction N 600), 1973
- 213 “Sheets from Lucobit 1210 designed for sealing of embankment dams” (St. Martin), 1973
- 217 “Covers from Lucobit 1210 designed for reconstruction of superstructures” (Nearby Salzburg), 1972
- 219 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Construction D 107), 1973
- 232 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Construction H 612), 1973
- 234 “Sheets from Lucobit 1210 for sealing of tank roofs” (Construction W 37), 1973
- 235 “Sheets from Lucobit 1210 designed for covering of flat roofs” (Construction W 133), 1973
- “Practical Test at the equator”, 120 km of canal lining with Lucobit, 1980 [14]
- “New ways of storing liquid gas – underground steel tank with plastic corrosion protection”, 1984 [15]

10) Object study

Reservoir “Kell am See”

In 1971 the city of “Kell am See” built a reservoir for recreational purposes with an impoundment volume of some 540,000 m^3 and a surface of approx. 130,000 m^2. The reservoir is sealed off with an artificial embankment dam that is 15 m high and 200 m long. The embankment dam was sealed with Lucobit sheets that are 2.0 cm thick and textured on their un-

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derside. Additionally, it was furnished with a protective layer and covered with concrete interlocking pavers (Image 13).

Image 13: Sealing of embankment dam at "Keller Stausee" with sealing sheets made from Lucobit 1210, 1971

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Approximately every ten years the construction is subject to comprehensive safety inspections in which the deterioration process of the installed sealing sheets is inspected.

In 2004 the sealing has been excavated and a sample has been taken for further laboratory tests (Image 14). The samples showed no damages whatsoever. After they were cleaned they practically looked as if they were in new condition.

The point from which the samples were taken was re-closed by means of building up new material using hot gas welding equipment following a previous welding attempt. The connection between the old and new materials was made without any difficulties leading to a clean, homogeneous bond, guaranteeing the required seam strength.

Image 14: Extraction of material sample from the sealing at the "Embankment Dam Kell" and subsequent closing of the hole by means of hot gas welding, 2004.

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11) Conclusion

For some 40 years, plastic sealing sheeting made from ECB (Lucobit® 1210) is used in civil engineering to efficiently seal off flat roofs, patios, tunnels, dams, ponds, reservoirs, landfills and many other constructions. Worldwide over 100 million m^2 of Lucobit sealing sheets have been installed to date.

When choosing and dimensioning the sealing sheets it is necessary to consider not only the material-specific requirements given in relevant Guidelines and Regulations but also the project-related strains e.g.:

- Permanent stress
- Permanent temperatures
- Composition of the surrounding medium

ECB sealing sheets (Lucobit 1210) are applicable under all common operating conditions of underground constructions or geotechnics (earthworks and hydraulic engineering).

ECB sealing sheets are resistant against decomposition, microbes, termites and rodents as well as against root penetration. Lucobit is resistant against common constructional substances like water, aqueous solutions of salts and diluted acids and bases (alkalis).

ECB sealing sheets can be suitably welded – whether in new conditions or after decades in use – with a hot gas welding equipment or hot gas and hot wedge welding machine ([4], [5], [12], [19]).

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12) Documents

The following documents were used for the composition of this report

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[3] Technical Data Sheet "Lucobit 1210", BASF AG, January 1975
[4] Technical Information "Sheets from Lucobit 1210 (ECB) for roof sealing", BASF AG, January 1979
[5] Technical Information "Sealing membranes from Lucobit 1210 – Instruction manual for the laminary application with hot bitumen and hot gas welding", BASF AG, August 1971
[6] Wald, Kelcher "Profiled membranes and boards from Lucobit 1210 in use", "The Construction Trade", Volume 51, Issue 14/71, pages 1175-1183
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[12] Application Guideline ECB roof sheets, Version 1987, Research Group "Manufacturers of roof sheeting" in corporation with TAKK (Technical research group for plastic and rubber sheets)
[13] Reports about technical practice tests, BASF Special Application Units:

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- 234 "Sheets from Lucobit 1210 for sealing of tank roofs" (Construction W 37), 1973
- 235 "Sheets from Lucobit 1210 designed for covering of flat roofs" (Construction W 133), 1973

[14] "Practical Test at the equator", 120 km of canal lining with Lucobit, 1980

[15] "New ways of storing liquid gas – underground steel tank with plastic corrosion protection", 1984

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