STATE-OF-THE-ART REPORT

Polyurethanes in the Construction Industry and the Environment

2nd Edition, June 2012

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PREFACE

This State-of-the-Art Report, "Polyurethanes in the Construction Industry and the Environment", was prepared by a work group assigned by Deutsche Bauchemie's Expert Committee 5, "Polymers in Concrete Construction", discussed in Expert Committee 5 and adopted. Its purpose is to provide information for member companies as well as professionals in the field.

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Deutsche Bauchemie e.V. would be pleased if you would share your experience with this State-of-the-Art Report or would like to make comments which should be addressed to the main office in Frankfurt.

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1 INTRODUCTION

Polyurethanes were initially developed in Germany in 1937. Since the 1960s, the significance of this universal plastic has grown enormously.

Our lives would be difficult to imagine without polyurethanes. Goods used in daily life such as mattresses, shoe soles, refrigerator insulation and upholstery for furniture are made of this material as well as high-tech medical products, from artificial limbs to infusion tubes or technically sophisticated automobile components such as dashboards, car body parts or fenders. You will discover injection moulded parts, fibres or foams made of polyurethane in just about all areas. The annual production (in tonnes per year) world-wide is in the two-digit million range.

The fascination of this material is its variable properties. Through the selection and combination of hard and soft components, hardness, strength and elasticity can be adjusted in practically any way that is desired. Lightfastness, resistance to weather and colour stability can be ensured by UV-stable components, making it possible to formulate polyurethanes for the respective purposes.

In the construction industry, reactive systems are mainly used in paste or liquid form which are applied on site corresponding to the application. When worked at construction sites, special measures must be taken since only the correct mixing ratio of two-component products will achieve a fully cured product that corresponds to the requirements on elasticity, tightness and hardness as well as UV stability and colourfastness. When single component products are used, mixing is not necessary and curing takes place through a reaction with humidity. Special, single component products such as polyurethane dispersions (PUDs) are non-reactive systems and cure through physical drying. Cured (cross-linked) polyurethanes are always inert and physiologically safe.

Work with polyurethanes should be left to specialists – not only for technical reasons but also for health protection reasons. Contact with or intake of the product components may pose a health risk for the people who work with them. Notes on how to safely handle liquid, reactive polyurethane components are found in the Technical Data Sheets and Safety Data Sheets issued by the manufacturers and in advices provided by the employers' liability insurance association.

There are now also Environmental Product Declarations (EPDs) for a number of polyurethanes used in the construction industry. These model EPDs were prepared for Deutsche Bauchemie's member companies based on generally recognised and specific environmental data in accordance with the international standards ISO 14025 and EN 15804 and provide an assessment of sustainability based on their ecological balance throughout the entire life cycle of the products.

Polyurethanes have proved themselves in the construction industry for decades as high performance materials. The spectrum ranges from highly wear resistant and crack-bridging coatings for park garages and industrial floors or collecting tanks in chemical plants to tread-friendly, decorative floor coatings, e.g. for floors in sports halls or running tracks in stadiums all the way to jointless waterproofing for roofs, walls or bridges. But you also find polyurethanes in places where they are not always immediately visible such as liquid polymer waterproofing under structures, beneath tiles or in cracks that have been closed with expansion capable materials. In all of these applications, polyurethane systems continuously contribute to comfort of use and a longer service life of buildings.

2 CHEMICAL PRINCIPLES OF POLYURETHANE SYSTEMS

2.1 Definition of Polyurethanes

Normally, all materials cured with isocyanates are called polyurethanes but from a pure chemical standpoint there is a difference between polyureas and polyurethanes.

Due to the increasing use of polyurea products, a distinction has been made in recent years between the two classes of materials which made a new definition/seperation necessary. The following definitions are used by Deutsche Bauchemie's member companies:

- **Polyurethane**
  The cross-linking reaction takes place solely through polyols.
- **Polyurethane-Polyurea Hybrids**
  The cross-linking reaction takes place with both polyols and amines.
- **Polyurea**
  The cross-linking reaction takes place solely with amines (see also State-of-the-Art Report "Polyurea in the Construction Industry and the Environment").

Polyurethane-polyurea hybrids as well as moisture curing, single component polyurethanes are usually deemed polyurethanes because of their material properties.

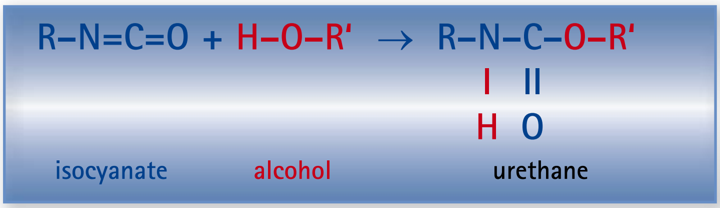
2.2 Reaction and Curing Mechanisms

Polyurethane systems are reactive systems. Curing takes place through conversion when the reaction capable (reactive) groups found in the components react with each other.

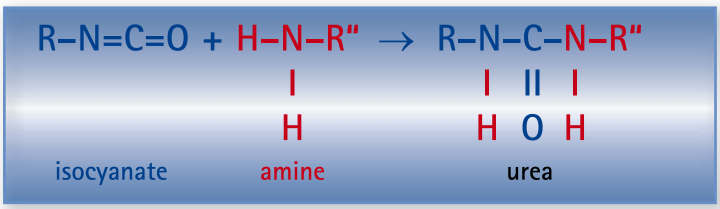
The curing reaction is always the conversion of polyisocyanates or diisocyanates (with isocyanate groups R-N=C=O as the reactive groups) with polyols (with hydroxyl groups R' OH or polyamines –R''-NH2).

The following reactions are typical:

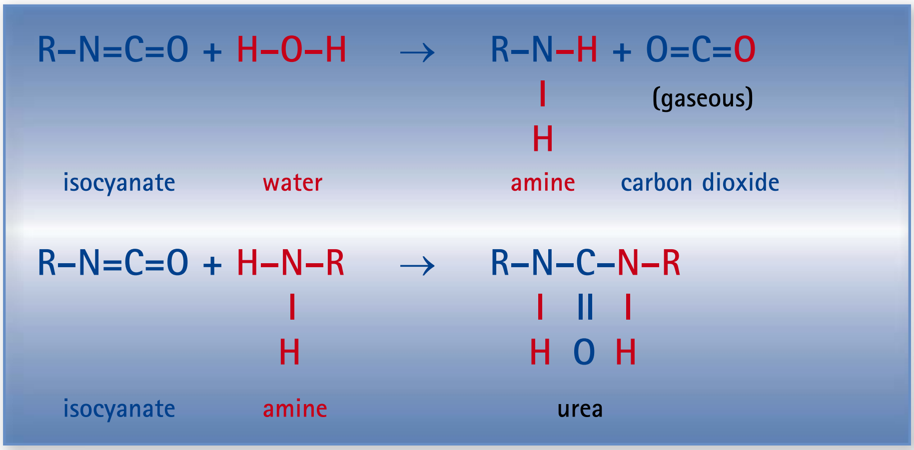
a) The conversion of isocyanate with alcohol (= polyol) produces a urethane:



b) The conversion of isocyanate with amine produces a urea compound:



A special case is when (poly)isocyanates convert with water (H_2O), during which amines result while carbon dioxide is released. Intermediate amines react with further isocyanates to form ureas in a reaction analogous to b):



In the case of 2K systems, working consists of mixing the liquid components and application of the mixed material. Curing takes place by a reaction of the reactive groups in the system.

With reactive, single component systems, moisture in the surrounding air reacts with the isocyanate groups or the latent hardener. The water-isocyanate reaction can be used to formulate water blown, environment-friendly foams in which volume expansion is achieved by the development of gaseous carbon dioxide and not through a physical foam process by mixing readily volatile propellants into the mixture. Systems that contain latent hardeners are especially designed to suppress the development of CO_2.

With non-reactive, single component systems (e.g. polyurethane dispersions), a chemical reaction does not take place; they cure through physical drying.

In the cured state, polyurethane systems essentially consist of a three-dimensional network with differently large cross-linking density ('mesh size'), depending on application. The functional groups have completed their reaction and are bound into the network. The material no longer contains reactive groups and is inert.

2.3 Formulation and Composition of the Liquid Components

2.3.1 General Composition

The **binders** used in polyurethane systems are the ingredients that essentially determine their properties. They carry the reactive groups which, by reacting with each other, create a three-dimensional, cross-linked skeleton.

Along with the reactive binder, properties are also adjusted through the addition of non-reactive constituents. To provide colour, **pigments** can be added to the binder and **fillers** are added to stabilise weathering properties or provide protection against corrosion. Fillers also help to reduce the shrinkage due to reaction and increase the hardness.

In general, **additives** are only used in small quantities (< 1 % by mass) for the purpose of catalysis, de-airing, to improve wetting properties, as an anti-settling agent, for UV stabilisation, etc. A large number of substance classes can be used to fine tune properties.

Dehydrating additives such as zeolites or oxazolidines are normally added to solvent-free, thick-layer systems > 500 µm, in the order of 3 - 5 % by mass. They bind water chemically or physically which may be present in the resins, pigments and fillers. This helps to prevent undesired reactions with moisture.

Some polyurethanes may also contain solvents or inert diluents. Both are used to adjust viscosity which, in turn, improves processing properties.

2.3.2 Binders in 2-Component Systems

The polyol based components are usually designated as the resin (in general component A) and the isocyanate based component as the hardener (component B).

In the past there were only solvent-free and solvent based, 2-component coating materials but during the last few years water based systems have increasingly become available in which the resin components are emulsified or dispersed in water.

Mechanical parameters such as elasticity/hardness and functional properties such as UV resistance/colourfastness, slip resistance or foam factors result from the resin and hardener combination used plus the interaction of further ingredients in the formulation.

▪ Resin Components

The reactive ingredients in the resin component are usually multi-functional polyols of different chain lengths, chemical properties and functionalities. These polyols are produced from petro-chemical or renewable raw materials and are available in solvent-free, solvent based or water based form.

In addition to these, amines combined with polyols are also used.

The following table gives an overview of the most frequently found types of polyols.

Type of polyol or amine	General property
Polyester	▪ very good weather resistance ▪ not saponification stable; not suitable for direct contact with concrete
Polyether	▪ saponification stable ▪ not resistant to weather ▪ suitable as a reactive diluent
Polyacrylate	▪ very good repair ability ▪ good weather resistance
Polycarbonate	▪ good weather resistance ▪ very good balance between flexibility and resistance against chemicals
Polyaspartic acid ester	▪ very fast cure at acceptable working time ▪ very good weather resistance ▪ suitable as a reactive diluent

- **Hardener component**

Multi-functional polyisocyanates or prepolymers are used as reactive substances.

The following table gives an overview of the types of isocyanates mainly used.

Basic structure	Type of monomer	Form used	General Property
Aromatic	MDI (Methyl diphenyl diisocyanate)	Polyisocyanate	▪ not colourfast/strong yellowing ▪ low viscosity
		Prepolymer	▪ not colourfast/strong yellowing ▪ medium to high viscosity
	TDI (Toluylene diisocyanate)	Polyisocyanate	▪ not colourfast/yellowing ▪ only available in a solvent based form
		Prepolymer	▪ not colourfast/yellowing ▪ medium to high viscosity
Aliphatic	HDI (Hexamethylene diisocyanate)	Polyisocyanate	▪ very good resistance to weather ▪ low to medium viscosity
		Prepolymer	▪ resistance to weather depending on polyol ▪ medium to higher viscosity
	IPDI (Isophorone diisocyanate)	Polyisocyanate	▪ very good resistance to weather ▪ higher viscosity ▪ additive to increase hardness
		Prepolymer	▪ resistance to weather depending on polyol ▪ higher viscosity ▪ used for membranes

2.3.3 Single Component Systems (1K)

Single component systems are usually made of prepolymers whose isocyanate groups cure through conversion with humidity.

Rapid skin formation on the surface is followed by slow full cure on the inside of the material. The humidity that is needed for the reaction must diffuse to the inside. Complete formation of properties usually takes place more slowly than with 2-component systems and strongly depends on temperature and humidity.

Attention should be paid that the generated carbon dioxide gas does not cause bubbles inside the material. Some systems may contain so-called latent hardeners such as oxazolidines which, activated by humidity, immediately react with the polyisocyanate.

Stoving systems in which the curing reaction is initiated by thermal energy are not normally used in construction applications. UV-curing systems are presently the subject of intensive research.

2.4 Physiological Assessment

2.4.1 Polyols

With the exception of a few special types, polyols usually are substances that are not subject to labelling.

Since polyols are high molecular compounds as a rule, they have very low vapour pressure and therefore there is hardly any risk of inhalation. Normally, polyols are no substances that are hazardous to water. In spite of this, it should be avoided that they reach aquatic environments or the sewers.

2.4.2 Polyisocyanates

Today, Polyisocyanates, polymers or oligomer isocyanates and their prepolymers are used in the construction industry.

In chemical plants designed for high process safety, raw material manufacturers also convert toxic raw materials into intermediate products for formulators which have considerably less risk potential which are used to produce end-products for the construction industry.

Users of the end-products thus receive synthetic products that are almost completely free of critical raw materials and can be applied manually.

Isocyanate prepolymers, for example, which are used as the hardener component in a coating for a parking garage contain less than one percent TDI. Another example is a weather resistant coating for balconies based on HDI which, as a rule, contains less than one percent of this monomer.

Systems based on MDI are often used in the construction industry. Since MDI is classified as a category 3 CMR substance, MDI based products fall under the German Chemical Prohibition Ordinance (ChemVerbotsV). This restricts their placement on the market (e.g. prohibition of self-service). When properly used, MDI poses no risk because of its very low volatility in the atmosphere (the workplace limit value is practically never reached at room temperature) [28].

When using reactive resin products in spraying applications, specific working safety measures must be generally taken such as effective extraction, the use of spraying booths as well as skin and respiratory protection. This also is relevant, of course, when isocyanate based products are applied by spraying.

Under very seldom circumstances such as accidents with intensive or repeated skin contact, aromatic isocyanates are being blamed as the cause for allergic asthma. People with a sensitive reaction to isocyanates may no longer work with construction products that contain isocyanates.

2.4.3 Amines

In some applications, sterically hindered, reaction controlled amines are used to achieve certain mechanical properties or to influence reactivity. Because they are alkaline, they may have an irritating or burning effect on skin and mucous membranes.

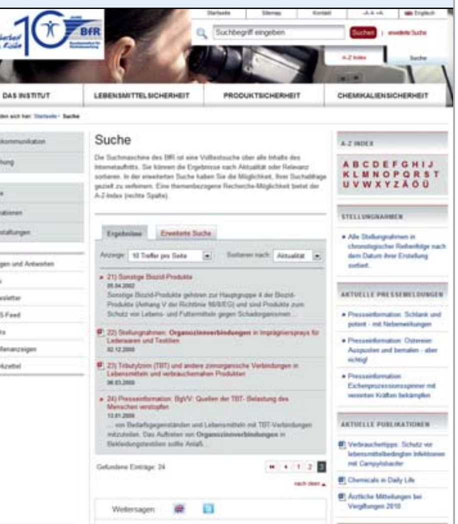
2.4.4 Fillers and Pigments

These predominately mineral substances are wet with liquid binder and therefore are not in dust form which could be inhaled. Coloured pigments that contain heavy metals and could harm health are no longer used on principle by Deutsche Bauchemie's member companies. Fillers and pigments therefore pose no or only a very slight risk for users and the environment

2.4.5 Additives, Inert Diluents and Solvents

Depending on the desired mode of action (e.g. as catalysts, surface-active substances, UV absorbers or light stabilizers), very different substance classes are used as **additives**. The small quantities that are added (as a rule < 1 %) reduce the significance of their possible physiological impact.

In special – predominantly aliphatic polyurethane resin systems, organo-tin compounds are used as catalysts. The concentration of tin in the normally used polyurethane products lies clearly below the limit value of 0.1 % by mass tin that restricts the sale of organo-tin compounds (Regulation 276/2010/EC). Depending on the application area, the delivery of articles which, for example, contain dibutyltin (DBT) in quantities above 0.1 % tin by mass, was prohibited after January 1, 2012 or will be in 2015.



According to a study by the German Federal Institute for Hygienic Consumer Protection and Veterinary Medicine (BgVV, today BfR) from May 2000 on organo-tin compounds in products used by consumers and in foods, the concentration of organo-tin compounds remains clearly below the Acceptable Daily Intake (ADI), even under the most unfavourable assumption that a good part of the quantity of organo-tin compounds found in the products ends up in the body of the organism. This value reflects the dosage that a human can take in day for day his/her entire life without expecting harmful effects. The conclusion of the assessment of the authority: The possible exposure to organo-tin compounds from plastics that come in contact with food, even in the most unfavourable case, contribute very little to total exposure and, in regard to combined effects, hardly make any difference [33].

All single component polyurethane coatings need moisture from their surroundings to cure. With classic single component polyurethanes, CO_2 results as a by-product which can lead to the formation of tiny bubbles in thicker layers. The reaction of an isocyanate with humidity is relatively slow. There are substance groups (for example oxazolidines) which produce an amine much more quickly with humidity. This amine then cures with the isocyanate. These substances are called **latent hardeners**. When latent hardeners are used, humidity is utilised to activate the latent hardener only after application which then immediately reacts with the isocyanate based binder. The release of CO_2 and consequently the undesired formation of bubbles inside the material can be prevented by this means.

The **inert diluents** that are still used today in some polyurethane systems are mostly assessed similar to polyols from a physiological standpoint. Compounds that are suspected of having a harmful effect on health or the environment (such as certain phthalates) are no longer used by Deutsche Bauchemie's member companies.

Solvents evaporate from the material during and after application. Therefore they must be assessed concerning the risk of air pollution and inhalation. For this reason, if possible, solvents are not used or their use is kept to a minimum. Solvent based systems (e.g. low viscosity, fast drying coatings) are labelled accordingly.
VOC emissions are dealt with in section 5.4.1.

2.4.6 Cured Systems

When properly cured, the reactive groups of isocyanates and polyols (as well as any amines that may be in the system) react to polyurethane or polyurea groups. Those are physiologically and ecologically inactive. After the evaporation of any solvents that might have been used and complete cure, there are no further health risks or even dangerous emissions from properly produced and cured polyurethane systems.

3 PROPERTIES AND RANGE OF USE OF POLYURETHANES

3.1 Performance of Polyurethanes

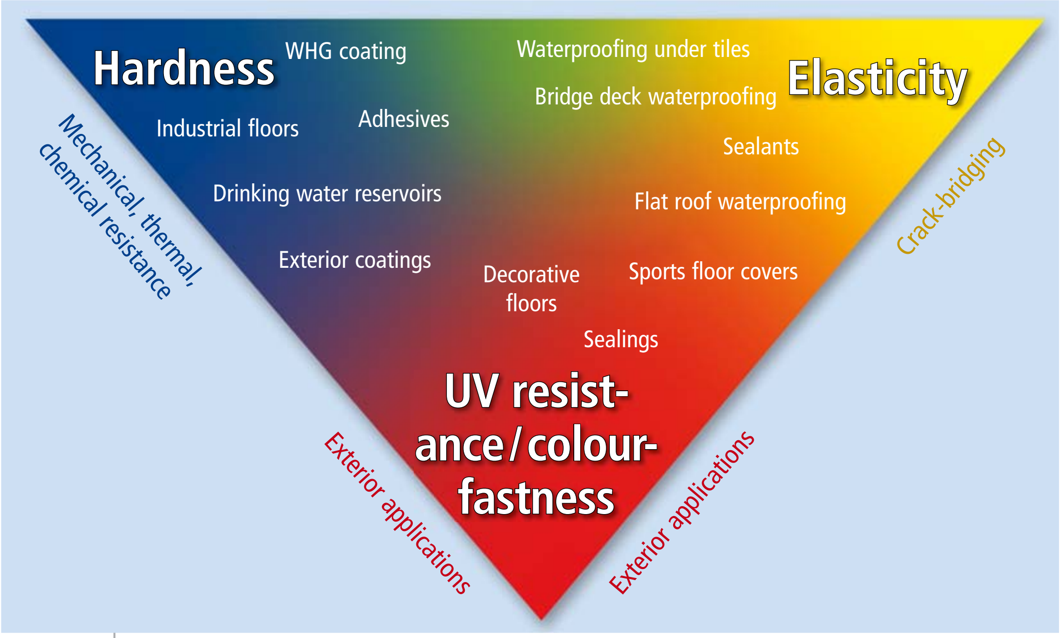
Polyurethanes are found everywhere in our daily lives. When it comes to versatility and performance, probably no other working material can compete with polyurethanes. Their enormous versatility results from the extensive range of resin and hardener components that are available and the many ways they can be combined (see section 2.3). By skillfully combining the resin and hardener, a product can be practically tailor-made for the desired application.

There are three material properties that are of decisive importance for the manifold applications of polyurethanes in the construction area which will be dealt with in more detail in the following sections:

- **Hardness**, which determines mechanical, thermal and chemical resistance
- **Elasticity**, which ensures the necessary expansion capacity or ability to bridge cracks when used for waterproofing
- **UV resistance/colourfastness**, which allow decorative as well as outdoor applications

Hardly for any other working material than polyurethanes it is possible to adjust the material properties – such as hardness and elasticity – over a wide range, from little to very high. This also applies to UV resistance and colourfastness which can also be formulated according to needs. To achieve the best possible product properties, the relationship of these three material properties must be finely balanced with each other, although in most cases one of the three properties will play a dominate role. An overview of the manifold applications of polyurethanes in the construction area and the dominating properties for these applications is presented in Figure 1.

Figure 1: Performance of polyurethanes – the connection between material properties and applications



Characteristic for industrial floors is their high mechanical, thermal and chemical resistance. This is achieved by the hardness of the products. On the other hand, when used for waterproofing, the elasticity of the material is the decisive characteristic: Only if the product is sufficiently elastic it will be able to bridge cracks that may form in the substrate and thus prevent the ingress of liquids into the substrate. With polyurethanes, even what seems to be contradicting requirements at first glance can be brought into perfect harmony with each other. In Germany, coatings used in areas that must comply with the Federal Water Management Act (WHG) must be sufficiently elastic to bridge cracks and yet have a certain hardness to sufficiently resist chemicals and mechanical loads. For many applications, UV resistance and colourfastness do not play an important role but these properties can also be realised through the use of suitable hardeners.

3.2 Coatings

High costs are usually involved when buildings are constructed. During the utilisation phase that follows, the buildings are subjected to many, often damaging influences. Along with environmental influences, mechanical and chemical loads also contribute to progressive destruction of unprotected building substance which results in rapid deterioration and time consuming repair measures which in turn are expensive.

It has proved to be much more sustainable to protect the building over the long term by using coatings on a polyurethane base which maintain the value of the building and save resources at the same time. A number of possible coatings systems on a polyurethane base are available for protecting floors and walls in new constructions as well as for repairing old structures.

Light loads can be counteracted through the application of a sealing (layer < 0.5 mm thick). Increasing requirements make thin-layer coatings (up to approx. 1 mm thick) or even several millimeter thick coatings necessary. With polyurethanes, heavily loadable, attractive and seamless coatings can be produced for practically any requirement imaginable. When certain parameters are observed, e.g. the dew point, polyurethane based coatings can also be worked in a wide climate range. Because of their short curing times, coated surfaces can be quickly utilised again. And should they become damaged while being used, coatings made of polyurethanes can be quickly and inexpensively repaired.

More than 40 years of experience prove the outstanding cost/utilisation ratio of polyurethanes in the construction industry.

3.2.1 Industrial Floors

Industrial floors in production halls, workshops but also at companies in the pharmaceutical and food industries are often subjected to heavy loads. Forklifts that weigh tonnes, impact loads when heavy goods are set down or fall on the floor and contamination with oils, fuels and chemicals take an extremely heavy toll on floors. Cleaning measures with hot steam and aggressive industrial cleaners just add to the toll. Because of their tough-elastic properties, polyurethane floor coatings have proved for years that they can reliably protect floors from these heavy loads. In spite of great hardness and resistance, they can also be formulated elastic at the same time so that these coatings can reliably bridge cracks that occur in the substrate. This protects the substrate from the ingress of liquids and increases the service life of the floor.

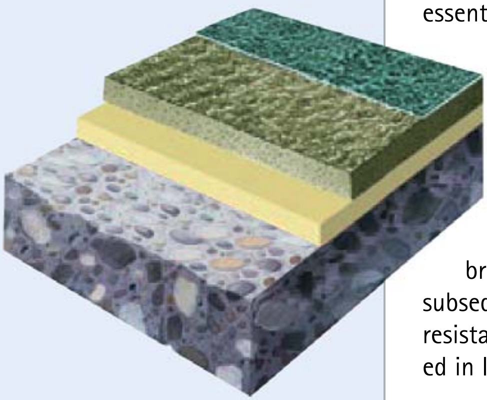
By selecting an appropriate blinding agent, these coatings can also be formulated slip-resistant which contributes to working safety.

Polyurethanes that are used as surface protection systems for concrete are subject to EN 1504-2 [5] and EN 13813 [4]).

3.2.2 Coatings for Parking Garages

Parking garages require special coatings to achieve the long service life for which they were designed. In these cases, it is important to protect the reinforcement in the concrete load-bearing structure from the ingress of de-icing salts, fuels and oils and, at the same time, to bridge cracks in the concrete substrate even at low temperatures. Since floor surfaces in parking garages have continuous vehicle traffic, they are also permanently subjected to heavy mechanical loads. The properties of coating systems that are essentially polyurethanes are outstanding for meeting these requirements. The construction of a typical parking garage coating system with a waterproofing layer, a wearing layer and sealant is shown in Figure 2.

Figure 2: Construction of a typical parking garage coating system – waterproofing layer, wearing layer and sealant



The combination of an elastic waterproofing layer on the one hand and the tough-elastic wearing layer on the other ensures high crack-bridging capacity and great abrasion resistance at the same time. By filling with quartz sand, permanently high mechanical resistance is achieved and by broadcasting with sand, additionally required slip-resistance is also guaranteed. The subsequently applied sealant is resistant to aggressive substances, ensures strong resistance to weather in outdoor areas and also allows decorative surfaces to be created in light colours with rich contrast that are pleasing to the eye.

Polyurethanes used in parking buildings are subject to the rules set out in EN 1504-2 [5]. In Germany additionally the DIN V 18026 has to be taken in to account.

3.2.3 Decorative Floor Coatings

Polyurethane flooring is not only found in industrial halls and warehouses or parking garages but also increasingly in doctor´s surgeries, clinics, law offices, schools, kindergartens and in private households. The pure technical advantages of polyurethane coatings applied in liquid form used to be the main reasons for their use, but today, aesthetic, ecological and occupational medicine aspects play a large role.

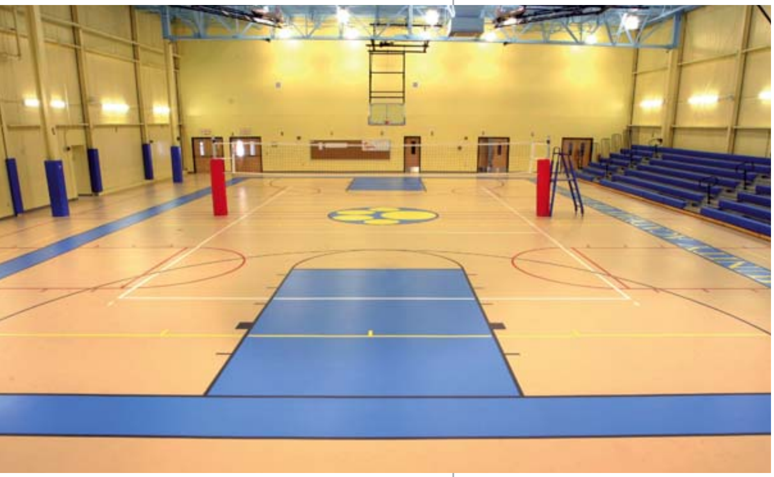
Users and specifiers of flooring systems used indoor want individual colours, different appearances of the surface, systems that do not yellow, are comfortable to walk on and release a minimum of emissions. Polyurethane technology is the perfect solution for these requirements. Careful selection of all the ingredients used for formulation offer maximum possibilities for decoration with minimum impairment of the indoor air caused by odours or harmful emissions. The emission behaviour of construction products is of special significance when they are used for habitable rooms. Therefore the DIBt decreed that products in accordance with EN 13813 used in habitable rooms must be approved. More information is found in section 5.2.1.

Also their only slight tendency to soil and the ease with which the surface can be cleaned which reduces the cost of maintenance is characteristic for polyurethane coatings. Additionally combined with a highly elastic sub-structure, polyurethane flooring has very good sound insulating properties when walked on. High point elasticity is easier on the locomotor system and makes walking and standing more comfortable. The durability of polyurethane industrial floors, well-known for many years, ensures a long service life.

3.2.4 Sports Floors

Polyurethane based running track covers were introduced in 1986 at the Olympic Games in Mexico and since then top level international sport would be unthinkable without them. Sports hall floor covers made of polyurethane are used for classic indoor sports such as basketball, handball or gymnastics but also for multi-purpose halls for school sport, mass sports and public events. Polyurethane covers have made an essential contribution in the record performances that are possible today in sports and easily fulfil all of the requirements of national and international standards (DIN 18032 [8], DIN18045 [9] and EN 14904 [13]).

The system used to construct a sports floor cover consists of a primer, a binder, adhesives, filling compounds, flow coatings as well as sealants and paints for marking lines on the floor. The typical combination of properties that these polyurethane products have – high tensile strength and, at the same time, expansion with good hardness – ensure a minimum loss of energy when running on them. This has made them absolutely the products of choice for years.



Polyurethane sports floor covers are placed without joints. They provide extremely hard wearing, tread-friendly and multi-functional systems with a long service life which can be used in all climate zones. And if, after years of intensive use, the cover needs to be renewed, this can be done inexpensively because the entire construction does not need to be removed and replaced which would be very time consuming and expensive.

Polyurethane covers for indoors and outdoors are appreciated by top athletes as well as amateurs because they are highly comfortable and minimise the risk of injury. Unlimited possibilities for coloured decoration and ease of cleaning are properties greatly appreciated by specifiers and sports facility operators.

3.2.5 Wall/Facade Coatings

Because their property profile offers many advantages, polyurethane resins are also used as wall coatings, not only indoors but also in outdoor areas directly exposed to weather. In indoor areas, polyurethane coatings are mainly found in the form of very high quality interior paints, e.g. for kitchens and baths but also for X-ray service areas and laboratories. Their excellent colourfastness, ability to be subjected to mechanical loads, resistance to chemicals and surface disinfectants as well as their ability to be decontaminated are convincing arguments and predestine them for long-term use on surfaces in outdoor areas directly exposed to weather. They have got a wide range of use, for example as graffiti protection for facades or for protecting the surfaces of civil engineering structures such as chimneys, cooling towers and tunnels. The products can be designed for all of the purposes mentioned: They can be formulated from rigid and less flexible all the way to very elastic and even crack-bridging.

The use of water based products for the above named applications is meanwhile widespread and in interior areas these products fulfil the requirements on very low VOC emissions (in accordance with AgBB, see section 5.4.1).

3.3 Waterproofing

3.3.1 Waterproofing under tiles

In conjunction with ceramic tiles, especially in areas with heavy chemical and mechanical loads or permanent water loads, liquid applied waterproofings made of polyurethane are used beneath tile covers. The waterproofing layer is applied between the concrete slab (or screed) and the cement bed for the tiles. After curing, these systems are particularly resistant against alkalis, aggressive cleaners, super heated steam, etc. and are also distinguished by high elasticity and tightness.

The requirements on waterproofing products are governed in ETAG 022 part 1 "Waterproofing Walls and Floors in Wet Rooms" [17] as well as in DIN 18195-2 [7]. Further information for waterproofing of balconies and terraces are found in a guideline issued by Deutsche Bauchemie [2].

3.3.2 Flat Roofs

Flat roofs place extreme requirements on waterproofing systems since these roofs are subjected to extreme climatic loads such as rain, temperature variations, wind and sunlight. If the roof construction has many breakthroughs (e.g. for air conditioning units, dome lights, chimneys, drains), a waterproofing system with conventional sheet roofing requires countless detail solutions with many welds which may represent weak points in the waterproofing system. Especially in these cases, waterproofing with a liquid, self levelling material, adapts to any irregularities in the roof construction and is also seamless ('cast in one') is especially durable and reliable. After curing, a waterproofing membrane results that is elastic at low temperatures and can easily compensate changes in dimensions of the roof construction caused by changes in temperature, the effects of wind or vibrations in the sub-construction.

Two important characteristics make polyurethane waterproofing an ideal working material for repairing roofs. First, depending on the state and the respective preparation of the substrate, the old waterproofing can usually remain in place. Second, damp roof insulation can still dry out after it has been coated due to the generally good water vapour diffusion capacity of the waterproofing.

The more than 25 years of positive experience in this area prove the durability of polyurethanes for these applications as well. By applying UV protection, resistance to UV radiation can be clearly improved even further. At the same time, individual wishes regarding colour are also possible. Flat roof waterproofing must also meet especially strict requirements on fire protection [16]. The rules to be observed in this area are especially ETAG 005 [16] as well as DIN 18195 [7] and DIN 18531 [10]. Further information on roof waterproofing are found in a guideline issued by Deutsche Bauchemie [2].

3.3.3 Balconies and Terraces

Waterproofing for these areas without protective cover must be especially hard wearing and resistant to mechanical as well as weather loads. In addition, they must also have the necessary elasticity to withstand structural movements in the substrate. Another decisive advantage of polyurethanes, especially when refurbishing, is that their weight per unit area is low and the applied system is thin. Decorative aspects also play a large role – balconies are often extended living rooms! There are also numerous textures and colours that can be selected for decoration.

Liquid plastics on a polyurethane base for waterproofing balconies and terraces are described in ETAG 005 [16] and/or EN 1504-2 [5].

3.3.4 Bridge Waterproofing

Highly reactive, sprayed elastomers made of polyurethane/polyurea hybrids play a dominate role today when waterproofing bridges in accordance with ZTV-ING, part 7, section 3 (ZTV-BEL-B 3 [23]). They allow seamless waterproofing in horizontal as well as vertical areas. In addition to the very high requirements on mechanical properties that are placed on spray-applied membranes (tensile strain behaviour), they must also be able to withstand very high temperatures since they are covered with poured asphalt. Along with the spray-applied elastomers, the waterproofing system consists of an epoxy resin based primer in accordance with TL/TP-BEL-EP and a bonding agent for the protective layer of poured asphalt.

The polyurethane products used for waterproofing bridges are governed throughout Europe by ETAG 033 [18].

3.4 Sealants and Joint Filling Compounds

Sealants and joint filling compounds (horizontal joints) are important for the durability of structures. They reliably and permanently prevent the ingress of moisture or ensure that no liquids leak from the structure into the ground or ground water. Damage caused by moisture is the type of damage most often found in construction. In spite of the fact that they make up only a small percentage of the structure as a whole, sealants and joint filling compounds have an important function in modern-day construction: Permanently elastic, they reliably seal 'movement compensating' construction elements, some of which with clearly different changes in length caused by temperature. This is also becoming more important in view of regulations to save energy in which the tightness of the external envelope plays an increasingly important role.

Good adhesion to various substrates and high mechanical strength are essential prerequisites for sealants and joint filling compounds. Slight injuries to the surface should not compromise the function of the waterproofing. Especially with polyurethane or polyurethane hybrid systems, optimum products can be produced for practically all applications in the waterproofing area because of the multitude of options for formulation. Very soft-elastic and weather resistant sealants for facades can be produced with these systems as well as products with high mechanical and chemical resistance which are needed for floor joints in parking garages or for waterproofing clarification plants. Today, user-friendly, single component systems are mostly used.

3.5 Water protection, Water, Sewage

3.5.1 Water Protection/Concrete container

Special requirements are placed on the tightness of concrete container that are used for storing, filling and transporting substances that are hazardous to water – in Germany so-called "LAU" facilities. The ability to bridge small cracks in concrete to prevent the container from leaking along with high resistance to the chemical substances being stored is decisive.

As a working material for collecting basins, uncoated concrete is not permanently resistant to a number of liquid chemicals and it is only deemed crack-free and liquid tight if it is especially dimensioned and executed. Collecting basins in facilities for storing, filling and transporting liquids that are hazardous to water must be effectively and permanently protected against the ingress of these substances. Chemical resistant and crack-bridging PU coatings meet the requirements for these areas and maintain the desired protective function over the desired service life, even when subjected to heavy mechanical loads, e.g. direct vehicle traffic.

In the scope of a reform of the federal system in Germany, an amendment of the Federal Water Act (WHG) went into force in March 2010. Formerly governed by the individual states, the implementation of WHG is now governed at the federal level.

Until this amendment, the construction and operation of facilities for storing, filling and transporting liquids that are hazardous to water were governed by WHG. The amendment now also sets out the requirements for shutting down such facilities. The requirements on the selection and application of coatings were formerly set out in paragraph § 19 which has now been replaced by paragraphs § 62 and § 63.

The use of polyurethane coatings for collecting basins ensures that the environment and groundwater are protected if a chemical tank should leak.

3.5.2 Drinking Water Reservoirs

Drinking water is the most important nutrient in the world and should be protected from unnecessary consumption and contamination accordingly.

Polyurethane coatings are increasingly being used for lining water pipes and reservoirs. Their ideal combination of abrasion resistance with good hardness along with their insensitivity to moisture make polyurethane coatings suitable especially for the repair of pipelines.

Polyurethane products that come in contact with water must meet special requirements regarding the release of organic substances. Since there is no consistent European regulation on construction products that come in contact with drinking water at present, products must meet national requirements. In Germany, this is governed by the "Coatings Guideline" issued by the Federal Environment Agency (UBA) (see UBA website at www.uba.de).

3.6 Adhesives

3.6.1 Tile adhesives

Tiles are used in swimming pools, bathrooms, entrance areas, for decorating kitchens and even facades: Tiled walls and floors are found everywhere because they are practical as well as attractive. No matter which purpose they fulfil, they should be as durable as possible, even under the most difficult conditions, e.g. when aggressive cleaners are used, if they are continuously under water or, as in the case of terrace tiles, when there are great differences in temperature (heated by sunshine and temperatures below -20 °C in winter).

Under such conditions, the tile adhesives used are subjected to heavy loads. Tile adhesives on a polyurethane base can be used for laying ceramic tiles, slabs and mosaics. Polyurethane adhesives are water resistant and water tight as well as frost resistant and they also have high tensile adhesion strength. They are deformable and compensate variations in temperature and stress in the substrate.

These products are especially suitable when there are time constraints when laying tiles because they achieve full loading capacity after just a short time. They can be used without a primer on many substrates and are also suitable for laying tiles on difficult and even vibrating substrates such as metals, PVC and plastic coated panels.

The general and special technical requirements on tile cements are found in EN 12004.

3.6.2 Parquet Adhesives

Particularly in installation of parquet, the elastic properties of the adhesive help distribute stress over a large area which prevents excessive stress in local areas of the substrate and the adhesive but still ensure that the parquet reliably adheres to the substrate in a shear resistant bond. Laying wood floors today would be unthinkable without hybrid polyurethane or polyurethane systems. By coordinating the strength and elasticity of the adhesive, the best possible bonding properties are guaranteed.

Another strong point of elastic adhesives is that they dampen vibrations. This property clearly reduces the transmission of sound compared to rigidly glued parquet floors. Increasing requirements in the area of sound insulation in construction areas have led to the increasing use of impact sound insulation systems. In addition to elastic bonding, foamed sound insulation mats from 3 - 5 mm thick can be glued to the sub-construction to increase impact sound insulation.

Great progress has been made during the last years when it comes to applying adhesives. Today, the application of adhesives is considerably simplified by the use of different kinds of equipment. Uniform application of adhesives in an ergonomic manner that is also easier on the joints of the person applying the adhesive and saves time as well are the key words at construction sites and of particular interest to those who lay parquet floors.

The requirements on adhesives for parquet floors are described in EN 14293.

3.7 Injections

Buildings are often subjected to loads through the ingress of water or other influences that cause damage, e.g. salts from the substrate. In spite of the greatest care, cracks, voids, gravel pockets, missing areas and leaking areas caused by the materials used can always occur in concrete or masonry work structures. It is often not possible to repair such damage from the outside, or only at considerable expense. However, the subsequent injection of a liquid polymer seal into the building substance can usually solve this problem.

PU systems are classically used for the injection of cracks to seal and close missing areas or to elastically connect construction elements. Small foam bubbles form in the dense resin structure when there is moisture in the building. Because of the fine bubble structure, elastic PU resins can widen with the crack or be compressed and thus follow the dynamics of the crack up to a certain extent.

Because of their tendency to foam, polyurethane resins can also reliably seal construction joints and particularly gravel pockets in buildings without causing corrosion of reinforcement in the area where walls rise from the floor which is especially susceptible.

Since polyurethanes form foam when they react with water, they can be especially formulated to resist the inrush of water in just seconds. These so-called fast expanding PU fillers or injection foam resins ensure disturbance-free curing of a slowly reacting PU resin for permanent sealing of the building. Expanding PU resins are also used to fill voids. Little material is needed for this and the material is not only thermally insulating but also economical.

Water inrush in active construction projects causes time delays and high costs. Polyurethanes are the answer since they cure in minutes, becoming a tough resin. They are used to seal quickly and stabilise tunnel structures and excavation pits when there is sudden water inrush. The PU resins are applied using efficient, 2-component units and develop their sealing and strengthening effect within minutes. This minimises down times caused by water inrush or instability.

Sealing is the main focus when injecting masonry work. The decisive quality criteria for a subsequently applied horizontal barrier are very low viscosity and good penetration, especially in the mortar areas of the masonry. Operating with "sealing off capillaries" as the principle of action Polyurethanes are a very durable waterproofing.. There is also no need to worry about a very high degree of moisture in the masonry since this does not restrict their use. PU resins not only reliably seal off capillary rising damp in the masonry work, they can also withstand stronger loads such as seepage water under pressure (as well as further loading cases found in DIN 18195).

The injection of cracks in concrete structures is governed by EN 1504-5 [5]. In Germany, the precursor national regulation was the Guideline for Protection and Repair of Concrete Structures issued by DAfStb (RL SIB) [1] and ZTV-Ing [21]. The essential requirements set out in the German regulations were included in EN 1504-5. The requirements on class D crack fillers were significantly increased in regard to the decisive property 'elasticity'. Compared to the Guideline for Protection and Repair of Concrete Structures, EN 1504-5, for example, requires higher elasticity at low temperatures and, at the same time, the smallest crack widths.

Polyurethanes can be formulated according to needs – from elastic-soft to tough all the way to hard. In keeping with the performance concept of the European standard EN1504-5, this provides new options. Crack applications such as frictional bonding of construction elements which could only be executed with other classes of working materials before can now be executed with PU systems. With polyurethanes, a wide spectrum of mechanical properties can be formulated in a wide range of reactivity.

4 APPLICATION – RISKS WHEN HANDLING

4.1 In General

As long as reactive resins have not yet cured, handling the individual components and working with the product may have risks.

Polyurethane systems are reactive systems. They may have an effect on the body through different forms of exposure, e.g. through contact with skin, if inhaled (particularly aerosols) or if swallowed. These risks are product-specific and described in sections 7 and 8 of the (extended) Safety Data Sheets. An overview of the risks are described in chapter 2.4 of this State-of-the-Art Report.

Technical and organisational measures should always be taken to combat such risks and supplemented by suitable personal protective equipment.

The working safety measures to be taken (ventilation, respiratory equipment) depend on the information given in the extended Safety Data Sheet and conditions at the site of use (e.g. dimensions of the room, air exchange rate, material output per hour) and should be determined in each individual case.

When solvent based products are used, suitable measures (ventilation, air extraction) must guarantee that the occupational exposure limit values are observed. Measures for protection against explosion may also be necessary.

If values cannot be maintained below the occupational exposure limit by technical means, respiratory equipment is essential. As a rule, an A type gas filter should be used for protection against solvent vapours although the gas filter class depends on the concentration of the harmful gas on site. When sprayed, an A1-B1-P2 combination filter should be used.

Depending on product and method of application, the material is applied with a filling knife/blade or roller, sprayed or injected.

Different protection measures may be required, depending on the application method, and should be strictly observed.

4.2 Preparing for Application

Careful planning and preparation of work avoid stress and also prevent dangerous situations from arising at the site of use.

Errors during working can be avoided by ensuring that the conditions for working are obeyed and preparatory works have been concluded.

Before work begins, the user should read the information in the Technical Data Sheet and Safety Data Sheet to be sure he knows how to handle the material properly and which protective equipment should be used.

Personal protective equipment should consist of at least tightly closing protective clothing (no skin should be exposed), safety shoes, protective glasses and protective gloves.

Proper protective gloves (EN 374) are usually made of nitrile rubber, butyl rubber or chloroprene rubber. When using solvent based products, protective gloves must also be resistant to the solvent used. The Safety Data Sheet provides information on suitable gloves.

While working, attention should be paid to a sufficient supply of fresh air in these spaces.

When handling PU products, wearing the right protective gloves in a tested quality is one of the most important protective measures to be taken.

4.3 Mixing

For Polyurethane products there are many different shapes and sizes of packaging, e.g. cartridges, 2-component buckets, combination containers, canisters, multi-chamber bags, etc.

Detailed instructions on opening the containers and mixing the components are found in the Technical Data Sheets issued by the manufacturer of the product and should be carefully followed.

Direct contact with the material should be strictly avoided by taking suitable protective measures. Protective clothing, protective glasses and protective gloves should always be worn.

When mixing the two components, the use of a tightly closing splash cover and a slow speed, infinitely adjustable mixer is recommended.

Normally, entire containers are mixed as delivered but if partial quantities are worked, special care should be taken.

Special protective equipment should always be used when work is carried out in poorly ventilated spaces and for pressure applications (e.g. injection resins).

4.4 Coating

The content of the container is poured onto the surface to be coated and distributed with suitable tools.

For ergonomic and safety reasons, it is preferable to work standing instead of on your knees, using tools with a long handle (e.g. squeegee, rubber wiper, roller or spiked roller).

4.5 Spray Application

For spraying applications, standard protective equipment is not sufficient and must be supplemented by suitable respiratory equipment and full body protection.

4.6 Injection

For protection against contact with the material caused by leaking packers, torn hoses, etc. a face mask (visor) should be worn in addition to the normal personal protection.

4.7 Cleaning Tools and Disposal of Waste at the Construction Site

For practical reasons, tools such as rollers, rubber wipers or spiked rollers are thrown away after use.

More expensive equipment is cleaned after use with a cleaning agent recommended by the manufacturer (see Technical Data Sheet). Especially when cleaning, complete personal protective equipment should be worn and the protective measures that should be taken for the specific piece of equipment should be observed (if applicable, explosion protection in case of solvents, compatibility with pump and spraying equipment components, etc.).

Leftover, cured polyurethane products are normally treated as trade waste similar to household waste. Waste that arises during the individual working steps must be collected separately and marked with the corresponding waste code numbers. After consulting with the disposal company, the materials are picked up in the assigned containers. The waste code numbers are found in the European Waste Catalogue (EWC).

To comply with regulations on packaging in Germany, the manufacturer and seller must take back packaging materials, also those in which goods with dangerous substances were packaged. Goods with dangerous substances are also understood as those products that are subject to the prohibition of self-service set out in the German Chemicals Prohibition Ordinance (ChemVerbotsV) [26].

To fulfil this obligation, manufacturers and sellers of polyurethane systems in Germany have concluded contracts with collection and recycling companies. If the packaging contained goods with dangerous substances, these are recycled through a separate disposal service (KBS: Kreislaufsystem Blechverpackungen Stahl für Metallverpackungen, Interseroh: Recycling für Kunststoffverpackungen, REPA-Sack-System für Kraftpapiersäcke) [KBS: recycling system for tin and steel metal packaging, Interseroh: recycling of plastic packaging, REPA Sack System for heavy duty paper bags]. A requirement for taking back containers and packaging is that they are completely empty. Containers and packaging are deemed completely empty when they are drip-free, have been scraped out and nothing runs out. Furthermore, the users of polyurethane systems must collect the different types of packaging (tin, plastic, paper, bags, etc.) separately for disposal. For further information on disposal, especially for the construction industry, go to www.deutsche-bauchemie.de under the heading “Packing/Disposal”.

4.8 Transport and Storage

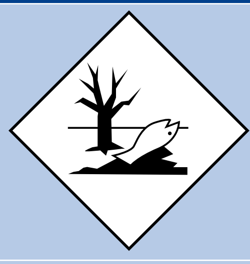
European Regulation No. 1272/2008 on implementation of the world-wide, uniform system (**G**lobally **H**armonized **S**ystem) for classification and labelling of substances and mixtures adopted by the UN has been in force since January 2008. By December 1, 2010, all substances placed on the market had to be reclassified and labelled in accordance with this system, the data registered in the ECHA data base and the respective Safety Data Sheets brought up to date. In the case of mixtures, which also include polyurethane reactive resin components, this must be carried out by June 1, 2015. The introduction of the GHS regulation, also called the Regulation on Classification, Labelling and Packaging (CLP) in Europe, means that new, characteristic pictograms concerning handling must be used.

4.8.1 Transport

When transporting PU resins and hardeners, suitable measures must be taken to protect humans and the environment. These measures depend on how hazardous the properties of the materials are. Information on this is provided by the manufacturer/suppliers in section 14 of the Safety Data Sheets (SDS). As a rule, the polyurethane components used in the construction industry, e.g. polyol resins and hardeners on an MDI base, are not dangerous goods as defined by regulations on dangerous goods. If these materials have harmful properties (e.g. are sensitising or irritate skin) or are hazardous to the environment (see SDS or marks on the label), these effects must be taken into account when transporting. The measures to be observed are the general safety provisions set out in the highway code, i.e. appropriate transport packaging is to be selected, the load must be secured during transport so that no goods are released.

Road transport is an essential means of transport for the construction industry in Europe and is governed by ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road). It is important that the people responsible for planning transports are familiar with ADR and all others involved in the transport of dangerous goods have been instructed in their respective activities.

Since the requirements of regulations on dangerous goods not only depend on the properties of the materials but also transport circumstances (e.g. quantity of the transported good, size of packages), the information given in this State-of-the-Art Report cannot replace the necessary knowledge on dangerous goods regulations.

Examples of dangerous goods classes for polyurethane components that require labelling		
		 
Class 8: Corrosive materials	Class 3: Flammable liquids	Class 9: Substances hazardous to the environment
e.g. because of an amine ingredient	e.g. because of a flammable solvent	e.g. because of ingredients that are hazardous to the environment

The requirements concerning dangerous goods are observed by the manufacturer of the products. If the user fills the products into different packages/containers or changes the original state of the packaging, the user is responsible for packaging that complies with the regulations.

The transport of products in delivery vans and automobiles may be exempt from these requirements or the requirements may be reduced. For further information, VCI has published the guideline "Beförderung gefährlicher Güter im PKW/Kombi" [41].

4.8.2 Storage

There are no special regulations on storage for substances and mixtures that do not require labelling. For substances and mixtures that are subject to dangerous goods regulations, especially solvent based components, the following rules must be observed:

a) Classification According to Flash Point and the Ordinance on Industrial Safety and Health

Depending on solvent and flash point, not only the polyisocyanate but also the polyol components may be assigned to a hazard class in Germany (extremely flammable (F+, R12), highly flammable (F, R11) or flammable (R10). These products are subject to the Ordinance on Industrial Safety and Health (BetrSichV) [25] and they include products with a flash point up to and including 55 °C. Solvent-free polyiso¬cyanates and resins normally have a flash point above 100 °C and are therefore not subject to BetrSichV. BetrSichV distinguishes between storage that is permit-free and storage that requires a permit. The decisive factor for assignment are the hazard classes named above for the products, the quantity being stored and the type of container used for storage. The requirements on facilities for storing combustible liquids in all of the above named classes are also found in TRbF 20 (Technical Rules for Combustible Liquids, Storage Facilities [32]) which will be implemented in the Technical Rules on Industrial Safety and Health (TRBetrSich) in the future.

b) Water Hazard Class (WHC – in German: WGK)

To assess any existing negative impact on the environment if leaked from the storage facility, water hazard classes are used. According to the general "Administrative Regulation of the German Federal Water Management Act for the Classification of Substances Hazardous to Water into Water Hazard Classes (VwVwS)" [24], liquid poly-isocyanates, polyols and their solutions are typically classified in water hazard class (WHC) 1 (slightly hazardous to water). The amines used may be classified as WHC 1, 2, or, in individual cases, also 3 (slightly hazardous, hazardous or severely hazardous). The measures to be taken depend on the quantities stored. For example, a collection room is prescribed as of the following quantities:

- WHC 1: more than 10,000 litres
- WHC 2: more than 1,000 litres

c) In General

All of the regulations on storage also apply to construction sites as well as containers that are not completely empty. In these cases, TRGS 510 applies.

Notes on storage are found in section 7 of the SDS.

4.9 Operating Instructions for Handling Polyurethanes (GISCODE)

Product Codes/ GISCODEs are based on the concept of placing products that have similar health risks, and thus require identical protective measures and rules of conduct, into groups. This reduces the great number of chemical products to just a few product groups. Deutsche Bauchemie in cooperation with GISBAU (German information system on dangerous substances maintained by the construction industry employers´ liability insurance associations) has divided polyurethane products with similar risks into product groups and so-called GISCODES have been assigned to these presently eight product groups. Notes on occupational safety and a model operating instruction compliant with the Hazardous Substance Ordinance (GefStoffV) were developed for each product group. These are compiled in a data base maintained by GISBAU, named "WINGIS" [32], and can be accessed at www.gisbau.de.

The manufacturers assign their products to the different GISCODE groups and place a corresponding note on the label, in the extended Safety Data Sheet and in the Technical Information Sheet. This allows a simple assessment of the products that can be used to comply with the GefStoffV [27].

4.10 REACH

The high technical standard of today's society is not at based on the use of chemicals as ingredients in a great number of products. Many articles we use in our daily lives, e.g. mobile phones, vehicles, fashionable clothing and, of course, the construction of buildings, would be impossible without the contribution of the chemical industry.

To ensure a high level of protection when producing substances, the members of the European Union have enacted the Chemicals Regulation REACH [30] which focuses on the protection of humans and the environment.

REACH came into force on June 1, 2007 and must be implemented by all companies in the EU. As of December 1, 2008 all substances manufactured in EU states or were imported into the EU had to be pre-registered and registered.

The REACH Regulation provides transition periods for registration – after pre-registration has been carried out.

To implement the REACH Regulation, the EU founded the European Chemicals Agency, abbreviated ECHA, located in Helsinki, especially for this purpose.

The first deadline for substances with annual tonnage of more than 1000 t per company ended on December 1, 2010. More than 4700 substances were registered, including many polyurethane raw materials.

Within the scope of substance registration, threshold values (DNELs: derived no effect levels und PNECs: predicted no effect concentration) must be ascertained from the information on substance properties for all chemicals classified as dangerous. Safe threshold values describe the concentrations or doses under which no harmful effects caused by the substance are expected for humans and the environment. The first extended Safety Data Sheets with exposure scenarios have been distributed.

The exposure scenarios describe the conditions under which the substance can be safely handled in regard to the environment, the work place and the user.

The exposure scenarios from the raw material suppliers especially contain information on safe conditions for use. Depending on how high the risks are in a use, the information may be very general to very specific. The entire life cycle of the substance, from production to use all the way to disposal, is covered. The first consequences of registration are now visible. The use of HDI uretdions for spraying applications, for example, has been restricted and is only possible if special protection measures are taken (see Safety Data Sheet).

As a rule, the manufacturers of polyurethane products belong to the group of downstream users since they are mostly formulators. Should the downstream user obtain products outside the EU, he must make sure that his sub-suppliers have pre-registered or registered the products he obtains to ensure the production of his products in the future. The downstream user is obligated to examine whether his applications are covered by the registration carried out by his sub-supplier based on the updated, expanded Safety Data Sheet for raw materials that are classified as hazardous. If not, he can either inform the raw material supplier of his use or he can carry out his own safety assessment. ECHA must be informed if a downstream user carries out his own safety assessment. Based on information provided by the sub-suppliers, the formulator prepares consolidated, extended Safety Data Sheets for his construction chemical formulations. All of this information aids the final user in handling the end product safely.

According to the REACH Regulation, the final users of polyurethane based products (applicators) are also downstream users. They must use products for which an extended Safety Data Sheet has been issued under the conditions described in the Safety Data Sheet. If this has been implemented, he has no further obligations as far as REACH is concerned.

5 POLYURETHANES IN THE ENVIRONMENT- ASPECTS CONCERING SUSTAINABILITY

5.1 Sustainable Construction

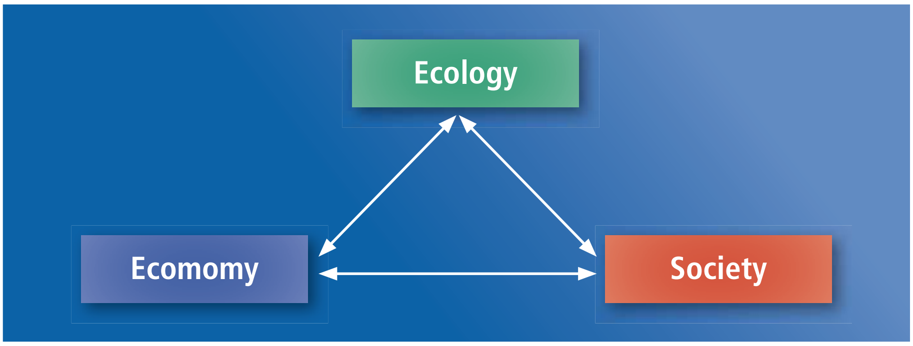
In the last 10 years, environmental awareness has become a mainstream issue in Europe and particularly in Germany. With the discussion on finite oil reserves, environmental protection and climate change, the complex term 'sustainability' is often used today in everyday language.

Historically, in Germany at least, the term sustainability was coined by Carl von Carlowitz. In 1713, in context of a lack of timber for the silver mines in the state of Saxony, he used the term 'sustainable forestry'. Von Carlowitz asserted that timber should only be felled in the amount that can grow back in the same period of time. Sustainability meant foregoing short-term profits in favour of long-term availability through reforestation and careful harvesting of timber [47].

Today, sustainability is discussed and demanded at international conferences on the environment and by the Expert Commission "World Commission on Environment and Development" of the United Nations founded in 1983. In the report, "Our Common Future", presented in 1987 [45], a look was taken for the first time at problem areas previously viewed separately such as the extinction of species, the spread of the desert, the debt crisis, conflicts that result in war, utilisation of space and poverty as interconnected effects for which a holistic solution should be sought. The unresolved tension between economic interests and environmental policy goals led to the action agenda adopted at the world summit in Rio in 1992 on sustainable development ("Agenda 21") [44].

The new European Construction Product Regulation promotes sustainability for the construction area. In addition to the essential requirements for buildings that already existed under the Construction Product Directive, a new basic requirement was added, No. 7 "Sustainable Utilisation of Natural Resources". Respective requirements corresponding to the international standards ISO 14025 and EN 15804 are to be taken up into the European standards for construction products. When this has been implemented, sustainable construction can then be assessed by a harmonised standard throughout Europe.

An example of sustainability is often presented as the interaction of ecology, economy and society [46]:



According to this definition, a process, a concept but also a product is designated 'sustainable' when all three areas are sufficiently taken into account.

Modern liquid plastics on a polyurethane base already correspond to this definition of sustainability today in many areas:

Ecology: The resin component (polyol) is often produced on the basis of natural, renewable plant oils (e.g. castor oil). A commercially available, 2-component, polyurethane coating often contains more than 50 % renewable raw materials (related to binder). In the cured state the products are ordinary building rubble and do not pose a risk to the environment.

Economy: Polyurethanes are long-lived products which provides a valuable contribution in protecting building substance (e.g. as a surface protection system or as injection material for cracked concrete), increasing service life and clearly improving the profitability of the building.

Holistic view of a building and its effect on the user and the environment over its entire life cycle.			
Protection goals	Protection of the environment Protection of natural resources	Reduction of life cycle costs Preservation of economic values	Safety of health/reliable comfort in the building Preserves social and cultural values
Assessment	Ecological quality 22.5 %	Economic quality 22.5 %	Socio-cultural and functional quality 22.5 %
	Technical quality	22.5 %	
	Process quality	10 %	
	Location quality		

Source: (Graubner [48])

Society: A simple example of the benefits of polyurethane chemical construction products to society are sports floors made of flexible polyurethane. Top performances in light athletics would not be possible without these special floors.

But sustainability in the construction chemical industry does not stop at products. Energy efficient plants as well as production processes in which auxiliary agents are used in closed circuit systems, practically eliminating all waste, are the standard in many operations today. The construction chemical industry makes a further contribution by promoting research to continuously reduce the quantity of fossil raw materials used and the carbon footprint of the products produced.

5.1.1 Life Cycle Assessment – Ecological Balance

In a life cycle assessment, the construction phase, utilisation phase with possible altered utilisation as well as demolition and disposal, i.e. the entire service life of a building or structure, is analysed. The consumption of resources and emissions into the environment during the entire manufacturing process are also taken into account. The resulting contributions to the greenhouse effect, eutrophication or acidification of waters can be quantified and assessed by the ecological balance method.

5.1.2 Building Certification

In Germany, it has become 'fashionable' today to have buildings certified based on their environmental properties. An entire service sector has grown around this. All of the building materials, construction products and processes used for the construction of the building and its maintenance are broken down according to their respective contribution. To assist quantitative assessment of the individual parts, Environmental Product Declarations (EDP) are consulted for the various construction products.

5.1.3 Environmental Product Declarations

Environmental Product Declarations (EPDs) are based on the international standards ISO 14025 and EN 15804. The environmental properties of a construction product during its entire life cycle are compiled in the EPDs in a standardised manner.

In the Construction Product Regulation, a new basic requirement was added – Basic Requirement No 7 – "Sustainable Utilisation of Natural Resources". To meet this requirement, EDPs in accordance with EN 15804 are to be used as an element of a harmonised procedure for the assessment of sustainable construction.

Model EPDs prepared by an independent consultant for Deutsche Bauchemie's member companies will be provided for the different polyurethane groups used in the construction area and are certified by the Institute Construction and Environment (IBU).

For more information, go to www.deutsche-bauchemie.de

5.2 Influences on the Environment during the Utilisation Phase

5.2.1 Quality of Indoor Air – VOC

The quality of air in living spaces and other indoor rooms is a subject that the public is beginning to pay more and more attention to. The increased awareness of people who work with chemical construction products as well as the occupants of rooms in which these products have been used prompted manufacturers to develop products that are not only better from a technical standpoint but also have less VOC emissions.

Aside from utilisation, the quality of indoor air is influenced by parameters such as temperature, humidity, air currents and, most importantly, the emission behaviour of all objects in the room as well as the construction products used. To establish the fundamentals for a uniform and reproducible evaluation of emission into indoor air through volatile organic compounds (VOC) from construction products, the "Committee for Health-Related Evaluation of Emissions of Volatile Organic Compounds (VOC and SVOC) from Building Products" (AgBB) developed criteria for testing and an evaluation scheme. The evaluation scheme sets quality standards relevant to health for use indoors and fosters the future development of particularly low-VOC products. Similar evaluation schemes have been introduced in other European countries or are in preparation and are presently in the process of being harmonised in Europe [20].

The German Institute of Construction Technology (DIBt) has adopted "Approval Principles for the Health-Related Assessment of Construction Products Used Indoors" [19b] which governs testing and evaluation of emission behaviour in general. For certain product groups and applications, National Technical Approvals with proof of emission behaviour are already required. Among these are synthetic resin screeds according to EN 13813 when used in habitable rooms. When used in industrial and trade halls, e.g. production and assembly halls or warehouses, emissions from construction products play only a subordinate role regarding air quality and an approval is not required for products used in these areas.

5.2.2 Surface Water, Soil, Ground Water

According to provisions of the German Federal Water Management Act (WHG) and the German Federal Soil Protection Act (BBodSchG), harmful changes to ground water and/or soil must be prevented or sufficiently reduced so that there is no negative impact on the natural habitat.

A concept to realise this requirement and thus assess construction products was developed by the German Institute of Construction Technology in "Principles for Assessing the Effects of Construction Products on Soil and Ground Water" – May 2009 [19a]. Taking current legislation on soil, water and waste into account, these principles describe general criteria for testing and assessment for site-independent evaluation of the effects on soil and ground water.

5.2.3 Behaviour in Case of Fire

Like all organic substances, polyurethanes are combustible on principle but the behaviour of a material in case of fire is not just a property of the material; it is also influenced by the thickness of the layer and type of substrate.

Polyurethane products that have not been formulated with flame resistant properties fulfil, as a minimum, the requirements for the European fire rating E or Efl (inflammable) according to EN 13501-1. But polyurethanes can also be formulated flame resistant so that they meet the requirements for higher reaction to fire classes. Polyurethane coatings can even be formulated to correspond to DIN 4102-7.

"Behaviour in case of fire" should always be distinguished from fire protection. The purpose of fire protection coatings is to protect their substrate (wood or steel) as long as possible from the high temperatures created by a fire and thus lengthen the time a building can maintain its structural stability. This type of functional polyurethane products are also available on the market.

5.2.4 Recovery and Recycling

According to our state of knowledge today, in general no harmful effects on the environment are to be expected when building elements to which cured polyurethanes adhere are recovered and recycled.

Since cured polyurethanes are elastomers or tough-elastic thermosets, they should not release hazardous substances or have a negative effect on the recycled material during the crushing process. In the case of polyurethane products that contain critical ingredients that fall under the REACH Regulation, the measures to be taken in regard to recovery and recycling described in the exposure scenarios of the extended Safety Data Sheets should be observed.

When sanding old coatings on a polyurethane base, fine dust that could penetrate the alveoli may be produced. Inhalation of this fine dust can be prevented by wearing a face mask with particle filter. Safety measures against explosion capable dust mixtures should also be taken.

Because of the energy content of polyurethane systems, thermal utilisation of recycled material with a correspondingly high content is also a reasonable recycling alternative.

6 CONCLUSION

Due to their outstanding mechanical and chemical properties, polyurethanes have proved themselves in a multitude of applications in the construction industry.

Particularly in recent years, the manufacturers of chemical construction products have not only focused on technical aspects but increasingly on environmental aspects and have invested in a great number of environment-friendly developments:

- Products on a renewable raw material base are increasingly being used.
- The use of solvents has strongly declined.
- Most of the products are low-emission.
- Products in contact with soil and ground water have been optimised so that the release of substances relevant to the environment is minimal, even in the placement phase.

Modern construction chemical coatings and waterproofing made of polyurethane save resources, protect our buildings, extend their service life and contribute to preserving their value, all of which meet the definition of sustainable construction.

Special operations that are aware of their responsibility ensure that there is no risk for humans or the environment when these products are used.

With their high quality standards, the member companies of Deutsche Bauchemie e.V. ensure the greatest possible safety for users, consumers and the environment.

7 FURTHER LITERATURE

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- **Application – Risks when handling**

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DEFINITIONS OF TERMS

The list of definitions of terms makes no claim of being complete. The designations of chemicals are not explained. Further terms are found in a glossary maintained on the Deutsche Bauchemie e.V. website at www.deutsche-bauchemie.de.

additive	A substance that is added to other substances or products in small quantities to alter their properties in a certain way
aerosol	Air with suspended particles made of finely distributed liquids or solids
aliphatic compounds	A class of substances in organic chemistry consisting of straight or more or less branched hydrocarbon chains
allergies	The reaction of especially sensitive persons to certain allergens. The severity of the reaction is independent of the concentration of the allergen. Skin, eyes and the respiratory tract are mainly affected.
aromatics	Class of substances in organic chemistry, e.g. benzene and its derivatives
biuret	A reactive isocyanate on a urea base
catalysis	Acceleration of a reaction by adding small quantities of substances with an activating effect (catalysts)
Chemicals Prohibition Ordinance (ChemVerbotsV)	German ordinance on the prohibition and restriction of placing hazardous substances, preparations and goods on the market in accordance the German Chemicals Act
CMR substance	Substance classified as carcinogenic, mutagenic or reprotoxic
DNEL	Derived no effect levels – derived, safe threshold values – values below which no effects on human health are expected
ECHA	European Chemicals Agency
ETAG	European Technical Approval Guideline
filler	Solid aggregates
functional groups	Groups of reactive molecules attached to a skeleton that are characteristic for a substance class
GISBAU	A hazardous substance information system created by the German building industry trade association
GISCODE	Classification system in GISBAU to classify product groups according to their hazard potential
hydrocarbons	Organic compounds consisting of the elements carbon and hydrogen
inert substances	Substances which under normal circumstances do not take part in chemical or biochemical reactions or are completely cured
inhalation toxicity	Toxic effect if inhaled
KBS	Recycling system for tin and steel packaging
latent hardener	Literally: hidden but existent hardener; chemically: a hardener that only becomes active after reacting with water
monomers	Molecules of low molecular weight capable of reacting with different molecules of low molecular weight to form a polymer

occupational exposure limit value The occupational exposure limit value is the weighted average concentration over time of a substance in the air at the work place at which acute or chronic harm of the health of employees is not to be expected. As a rule, determination is based on eight hours of exposure five days a week during total working life. The occupational exposure limit value is given in mg/m^3 and ml/m^3 (ppm). In Germany, this term (AGW) was introduced on January 1, 2005 with the new version of the Hazardous Substances Ordinance (GefStoffV). It replaced the maximum work place concentration (MAK) and the Technical Reference Concentration (TRK).

oral Uptake of substances, particles, etc. through the mouth

oxazolidines See latent hardener

pH value The negative decimal logarithm of the concentration of hydrogen ions in an aqueous medium. pH 7 stands for a neutral reaction, pH values < 7 are acidic and pH values > 7 are alkaline reactions.

pigment Solid that adds colour

PNEC Predicted No Effect Concentration – an ecotoxicological measure for multiple species systems – concentration-effect relation

polymers Substances that result through polymerisation i.e. through a chemical process in which many small molecules (monomers) of one or several substances combine into large molecules with new properties.

prepolymer Prepolymers result through a precursor reaction of part of the reactive groups

REACH Regulation (EC) No. 1907/2006 of the European Parliament and Council from December 18, 2006 on registration, evaluation, approval and restriction of chemical substances (REACH Regulation)

self-assessment Derivation of water hazard classes according to a special evaluation scheme recognised by authorities (in Germany).

sensitisation Repeated action of an exogenic substance on an organism which then shows a specific, changed reaction if the substance is again brought in contact with the organism. Sensitisation precedes an allergy.

thermosets Plastics with tightly cross-linked molecule chains that are no longer pliable in the cured state

TL/TP-BEL-EP German Technical Delivery Terms/Technical Test Provisions for bridge deck overlays on concrete

toxicology Study of the adverse effects of substances (poisons, toxins) on living organisms.

TRGS German abbreviation for Technical Rules for Hazardous Substances

viscosity Physical measurement that describes the thickness or thinness of liquids.

VOC Volatile organic compound(s)

Water hazard classes (WHC) Substances that are able to permanently change the physical, chemical or biological state of water are assigned to water hazard classes (in German WGK) in compliance with § 62f of the German Water Resources Act (WHG):

WGK 1: slightly hazardous to water

WGK 2: hazardous to water

WGK 3: severely hazardous to water

WHG Abbreviation for German Water Management Act

zeolites Crystalline powder with the ability to store water

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