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Topics: School, Training, Education

## Construction Chemistry Teaching Material

# From Caves to Skyscrapers

This teaching material was prepared in cooperation with Deutsche Bauchemie (DBC) and can also be downloaded at [www.vci.de/fonds](http://www.vci.de/fonds).

This teaching material as well as the worksheets and experiments were prepared in cooperation with Deutsche Bauchemie (DBC) and can be downloaded at [www.vci.de/fonds](http://www.vci.de/fonds) and [www.deutsche-bauchemie.com/publications/english/all/](http://www.deutsche-bauchemie.com/publications/english/all/).

Accountable for the translation in English is Deutsche Bauchemie (DBC)



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5	TRANSPORT OF THE EMMAUS CHURCH	LOWER SECONDARY	4.2
6	ALL-PURPOSE CONSTRUCTION CHEMICAL ADHESIVE: MORTAR	LOWER SECONDARY	4.2.1
7	POLYURETHANE	UPPER SECONDARY	4.3.1
8	CORROSION OF REINFORCED CONCRETE CAUSED BY CARBONATION	UPPER SECONDARY	4.1.1
9	CORROSION OF REINFORCEMENT STEEL CAUSED BY CHLORIDE IONS	UPPER SECONDARY	4.1.1
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To facilitate readability, the masculine language form has been used throughout this booklet. Terms marked with an asterisk \* can be looked up in the Glossary.

Who thinks about chemistry when admiring architecture? Probably not very many people do but without chemistry nothing could be built: No streets, bridges or airports, no stores, no buildings for leisure or sporting activities and certainly no leading-edge construction projects such as the highest building in the world, the more than 800 metre tall skyscraper Burj Khalifa in Dubai. Conventional building materials such as lime, sand, cement, gypsum or wood no longer suffice by themselves; the right admixtures are needed to give a building material special capabilities. For example concrete plasticizers and superplasticizers that make concrete easier to use, or retarders that delay hardening of the concrete. Accelerators have just the opposite effect and in extreme cases they can even make concrete set in just a few seconds.

“Threat factors” (environmental influences) such as water, salts or highly fluctuating temperatures put a strain on buildings. It is therefore not just a question of selecting the right building materials. Maintenance and repair work are also important aspects if a building is to remain intact for a long time. The question of whether “prophylaxis” or “therapy” then also presents itself.

The didactic concept of this information series presents three areas: “Building materials”, “Threats” and “Prophylaxis or Therapy”.

This is where the chemistry of substances, physical characteristics, chemical reactions and strategies that result from learning come together and numerous suggestions for experiments are given. Of special didactic significance are the pilot experiments which emphasise function or mode of action.

Through experimental investigation of the effect of admixtures on concrete, it can be shown, for example, that building materials can be given special capabilities if the right ingredients are used.

As an example of a “threat” to a building, the corrosion of steel reinforcement caused by carbonation in the composite material reinforced concrete can be studied in class.

An example in the “therapy” area is a pilot experiment that models the effect of restoration render on damp walls. The aspect of “salt-storing restoration render” provides a link to the subject of “salts” suitable for Secondary I level. If the strategy of gaining knowledge and phenomenological study of the results has priority, this example would also be suitable for beginner classes in the science fields.

Overall, many of the examples can be integrated in Secondary I level so that “construction chemistry” does not need to be reserved for Secondary II level (see the overview of different class levels found on page 3).

Basic concepts and scientific methods of chemistry can be experienced in an original context in conjunction with the subject of “construction chemistry” and contribute to the development of functional and scientific knowledge.





Homes, churches, castles, bridges – we all take these things for granted. It is hard to imagine that humans lived in caves, pits in the ground or beneath rock ledges just 20,000 years ago. But the desire for security and comfort increased over the course of centuries and humans started to build: First with wood, natural stone and loam, later with bricks and concrete. Lime and gypsum were used as a binder more than 10,000 years ago and about 2,000 years ago the Romans produced concrete made of burnt lime and clay minerals, sand and rubble stone.

### 2.1 Wood: The Oldest Building Material

Wood is inseparably linked to the development of mankind. The first wood houses were already built around the year 10,000 B.C. Wood was the most important building and heating material in ancient times and it was only in places where wood was plentiful that settlements developed. Its stability and strength made wood, along with stone, the ideal structural building and working material right up into the 19<sup>th</sup> century (framework construction). Today this raw material is more popular than ever: as an environment-friendly building material and as a CO<sub>2</sub> neutral source of energy. But frost, sunshine and moisture cause wood to age and it can also become infested with fungi and destroyed by insects and therefore needs protection. So very early, people discovered protective coatings such as lime paints. Today, the construction chemical industry offers a great variety of materials and systems to protect wood.



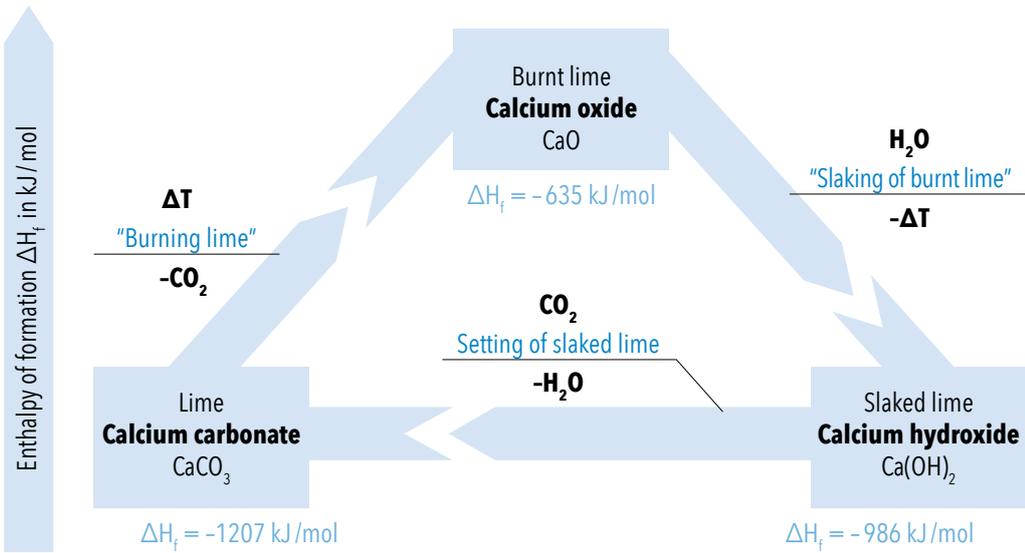
### 2.2 Loam: The Building Material of the Deserts

Along with wood, loam is mankind's oldest building material. Made of clay, silt and sand, it has been used for building since time immemorial and was an important building material in practically all ancient cultures. The roots of loam construction go back to the dry areas of the Middle and Near East. The first cities built by humans such as Jericho were built with loam; loam was also used as a building material for the Tower of Babylon, parts of the Chinese Wall as well as for large buildings such as the Mosque of Djenné in Mali. The fantastic old city of Sana'a in Yemen, a World Heritage Site, fascinates visitors to this day: Several hundred years ago, master builders erected high rise buildings and towers up to ten storeys high made of air-dried, loam brick. Humans learned very early how to fire loam (clay) to produce bricks that were less sensitive to water. Depending on firing temperature, very dense and resistant bricks were produced. If pure loam was used as a mortar for masonry work or as a render, animal hair was added in ancient times to prevent cracks. A water repelling effect (hydrophobization) was achieved by coating with oils and fats.



Old city of Sana'a in Yemen

The cycle of lime with enthalpy of formation  $\Delta H_f$



The enthalpy of formation  $\Delta H_f$  is the measure of energy required for the formation of a chemical compound from elements or the energy set free when a chemical compound is formed. With exothermic reactions, the enthalpy of formation is negative; with endothermic reactions it is positive.

### 2.3 Lime: From Shells to Building Lime

No one knows exactly when humans discovered that they could produce a binder that is ideal for producing mortar by burning natural limestone, then slaking (extinguishing) it with water and allowing it to harden in air. But finds of lime mortar in eastern Turkey show that this was known and used around 14,000 years ago. Lime is the oldest binder for masonry and render mortars. The Romans were the first to use lime on a large scale since the raw material limestone was available throughout the entire Roman Empire. As with loam, proteins were added to lime in ancient times to improve impermeability or oils to make them water repelling. So even these mixtures had properties similar to those of modern construction chemical products. Today as well, lime is one of the most important building materials, especially in the area of renders. It is also essential for the production of autoclaved aerated concrete\* and sand-lime brick.



Sea shells are made of lime



Stucco work made of gypsum

## 2.4 Gypsum: Thanks to Monasteries on the Road to Success

Another mineral binder is gypsum (calcium sulfate dihydrate). The oldest evidence found dates back to around 9,000 B.C.: in the city of Çatalhöyük in Asia minor, gypsum render was used as a substrate for decorative frescos. When building the pyramids, ancient Egyptians filled voids with a mixture of gypsum and lime. Knowledge about gypsum spread from the Greeks to the Romans and finally reached central and northern Europe but was forgotten for a while when the Romans left. Thanks to the monasteries, gypsum experienced a revival starting in the 11<sup>th</sup> century: Straw fibres and horse hair were mixed with gypsum, making it highly suitable for filling framework compartments in interior walls.

Gypsum is made by burning calcium sulfate scale (calcium sulfate dihydrate) but lower temperatures are needed compared to lime which makes production less time consuming. Gypsum has the advantage that it reacts and hardens very quickly which makes it possible to build faster. For the master builders of the Renaissance, Baroque, Rococo and Art Nouveau periods, gypsum was an important basic material. The multitude of forms used for these building styles was only possible with gypsum.

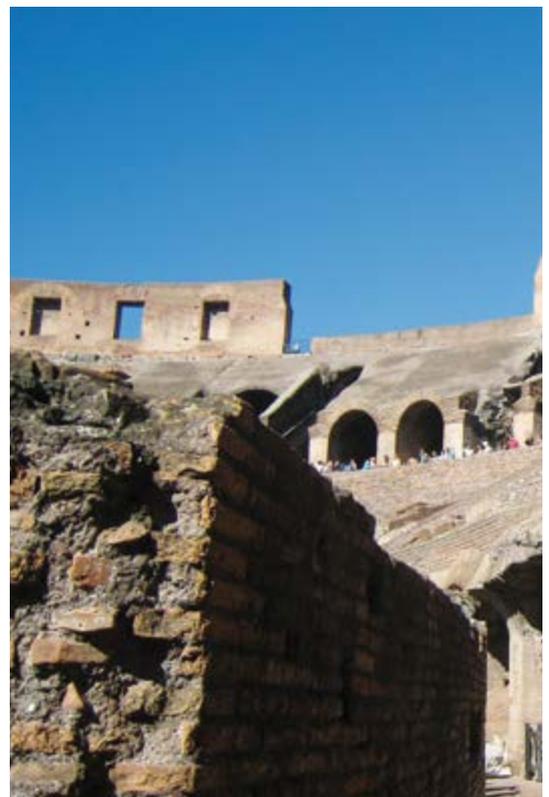
However, gypsum is not resistant to water and therefore only suitable for use in indoor areas.

## 2.5 Cement and Concrete: Classic Materials with the Best Future Prospects

For nearly 2,000 years it held the record: The dome of the Pantheon (120 A.D.) in Rome. Its free span of 43 metres was only exceeded several hundred years later in 1911 when the Centennial Hall was built in Breslau, Germany. The Roman cement used for the Pantheon, known as Opus Caementitium, is one of the most important inventions in the history of building. The Latin term is made up of the words "opus" (work/building) und "caementitium" (masonry stone/rubble stone).

### NOTE

Humans learned very early that building materials could be given special capabilities if the right ingredients were used. And that is exactly what the manufacturers of chemical construction products do today – they supply high-tech chemicals that are used as admixtures and additives to make modern building materials stronger, harder and more durable. Just small amounts suffice to considerably change the properties of concrete, sealing compounds or mortars.



Roman concrete, Colosseum

Sometimes experts even speak of a "revolution in building technology". Roman concrete was made of stone, sand, water, burnt lime and pozzolanas (substances erupted from volcanos which react with lime similar to cement) and harden – just like concrete today – to a synthetic stone. The Romans did not understand the underlying chemistry of the material, of course. The achievement of the Romans and their ancestors was to have developed concrete just by trial and error. They added milk, eggs, ox blood as well as a goat flour to concrete to make it easier to work, to make it more water impermeable or to achieve greater strength.

"Liquid stone" – was the designation given to Roman cement by Vitruv (approx. 70–10 B.C.), one of the great, master Roman builders.

There could hardly be a more precise and brief definition of this building material. If cement, water and aggregates such as gravel and sand are mixed, "normal" houses and buildings – ceilings, walls, supports, house driveways and garden ponds – can be built with this classic concrete.

The use of "construction chemicals" in the form of certain additives such as selected, fine materials and concrete admixtures is what makes the construction of dizzying skyscrapers, futuristic bridge constructions and monumental buildings, concrete roads, tunnels, clarification plants or lock constructions possible today.



Roman concrete in perfection: the Pantheon in Rome

🟡 TEACHER INFORMATION

- Worksheet 1: Building material corrosion
- Worksheet 2: Lime cycle and the use of lime in the construction of houses
- Experiment I: "Lime" as a binder for mortar – but which lime?
- Experiment IV: The construction of a model house and its aging

At first glance, construction chemicals are not necessarily evident at a building site but they are actually omnipresent. No house, no bridge, no television tower, no dam could be built without them. Highly complex buildings, increasingly bolder designs and shorter construction times; the construction chemical industry supplies tailor-made products to meet all of these requirements – from anti-graffiti coatings to custom-made admixtures for concrete, mortar and adhesives.

Representative for all large buildings, high-rise buildings, bridge and tunnel structures or swimming pools, the following chapter shows the construction of a house step by step. Using this house as an example, it will be explained which products are used in the different areas. In the case of other structures such as those mentioned above, many special products are used that are only required for these special cases. These will be discussed in Chapter 3.2. In Chapter 4, construction chemical products and their special properties will be presented individually.

The Use of Construction Chemical Products in a Modern Building



1. Thermal insulation p.18	2. Bonded waterproofing p.16
3. Tile cement p.16	4. Primer p.16
5. Render p. 40	6. Sound insulation p.16
7. Perimeter insulation p.15	8. Flow mortar p.16
9. Bitumen thick coating p.15	10. Concrete floor slab p.14



### 3.1 A House is Built

A house is constructed in many individual work steps. Craftsmen call these steps "works" – for example masonry works, dry lining works, concrete and reinforced concrete works or carpentry and timber construction works. Each of the works requires different building materials which are briefly presented in the following pages.

#### 3.1.1 Carcass

After the foundation pit has been excavated, work begins by laying the sewer system and drainage pipes which are made of concrete, stoneware or plastic.

##### ● Foundations, Ceilings and Walls

The foundations are then poured on which the load-bearing walls of the house will stand later. Today, foundations are always made of concrete – usually "unreinforced concrete" but also reinforced concrete\* for heavier loads.

A floor slab made of concrete is placed between or on the foundations. Service pipelines and sewer pipes rise out of the floor slab. Afterwards, concrete technicians or masons build the walls. These are either made of concrete or built stone on stone with masonry mortar. The formwork for the basement ceiling is set up, the steel reinforcement put in place and the concrete poured. After the concrete has hardened, the walls of the next storey are built. This process is repeated until the roof floor has been reached. The top of the house is completed by a roof structure which is built by a carpenter. To make the wood durable, it is impregnated with wood preservatives. Today, architects often decorate especially representative buildings with fair-faced concrete. The concrete used for this must not only be load-bearing and durable; it must also withstand the influences of weather and be attractive since, as its name indicates, it is directly visible. Fair-faced concrete should thus have the smoothest possible surface with few or only small pores. Coloured pigments can also be added to the concrete which allows the owner of the house to decorate the house as he pleases.

>> [Concrete 4.1](#); [Concrete Admixtures 4.1.1](#); [Mortar 4.2](#)

#### ILLUSTRATION 3

Pre-stressed concrete slab, reinforced concrete, concrete



• **Waterproofing the Basement**

Building is a battle against water! This old piece of wisdom concerning buildings makes it clear that water is the greatest enemy of all building materials and house owners. It attacks building materials, e.g. through corrosion, and causes deterioration of the building substance. That is why preventive waterproofing of a house to keep water out is extremely important and decisive for the durability of the entire construction. Water can ingress into the building from all sides through the foundations, the floor slab, basement walls and particularly the connecting areas of the individual building elements. These areas must be especially protected from the ingress of moisture. To make sure that moisture cannot penetrate into the walls and rise later in the event of damage, for example when a water pipe bursts, the walls are waterproofed with a so-called horizontal barrier. In the case of masonry walls, craftsmen create this barrier by placing a special, coated sheet of cardboard or a layer of waterproofing grout that sets by hydration\* in the masonry or on the floor slab. To make sure that moisture cannot penetrate through the walls from the outside, external walls are also waterproofed. A waterproofing render/repellent render, waterproofing grout or, especially if the basement is used as living space, a bitumen thick coating or liquid polymer are used for this.

>> [Waterproofing Grouts 4.2.2](#); [Reactive Resins 4.3.1](#); [Bitumen 4.6](#)

• **Waterproofing the Roof**

In areas where chimneys or ventilating pipes protrude from the roof, craftsmen must make especially sure that rain water cannot enter. These areas are sealed, for example, with liquid polymers or with permanently elastic joint sealing compounds and adhesives that expand and contract in heat and cold without detaching. Chimney bricks that rise from the roof are treated with special agents to make them water repelling.



Application of a bitumen thick coating



### 3.1.2 Finishing

Houses are finished individually according to the desires of the owner and it is these finishing works that determine the final appearance of the house. Service mains are installed, walls and floors receive their final surface, windows are installed, tiles are laid in the kitchen and bath and floors are laid.

#### ● Floors, Walls and Ceilings

After the heating system, water pipes and electric wiring have been installed, the openings through ceilings and walls and slits that were made for electric cables and heating pipes are filled or closed with repair mortar or dry concrete. Craftsmen also often use mounting foams to close these openings. The stucco worker, also called plasterer in some regions, finishes walls and ceilings by applying premixed renders on a gypsum or lime base or, in damp rooms, render on a cement base. A wide range of different types of renders is available for different substrates and special building elements. Bonding layers on a polymer or cement base are also often used first as an intermediate layer to improve the adhesion of the render to the substrate.

Before painters can begin their work, defects in the render such as chipped areas, grooves and roughness are filled and smoothed with filling compounds (wall/ceiling filler). During this time, work is also continued on the floors in the carcass which are constructed of several layers. The screed layer places a layer of sound insulation first to minimise the

sounds of walking. A waterproofing membrane or layer of waterproofing paper is then laid over the insulation before wet screed on a cement or anhydrite (gypsum) base\* is placed.

But that's not all. Once the screed has hardened, the surface is levelled by covering with a flow filler. This layer ensures that a very smooth and even surface is achieved that is easy to walk or play on. Screed alone would be too rough unless it is smoothed with special machines right after it is placed.

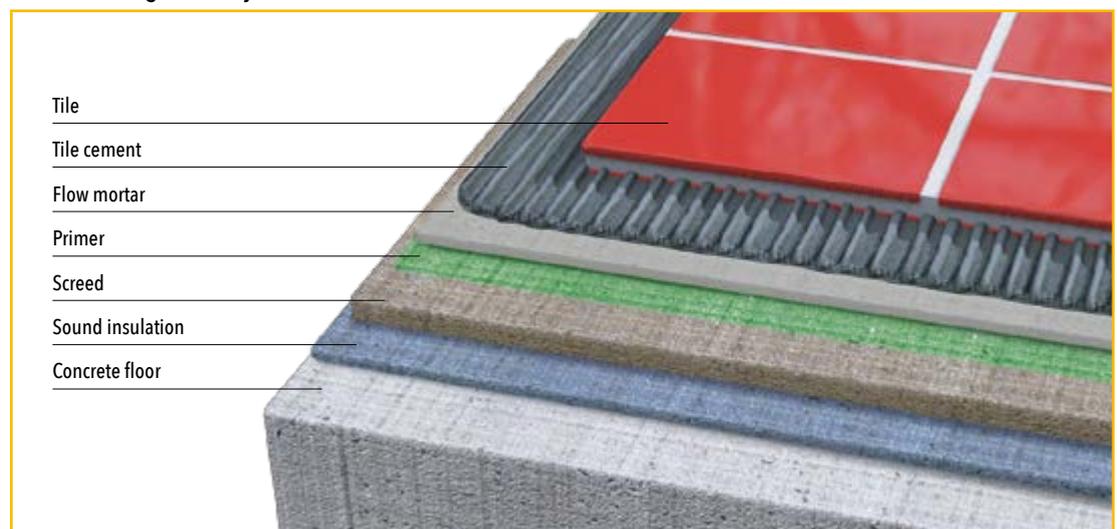
The floor layer then places the final floor cover, e.g. carpeting, parquet or tiles, over the hardened layer of flow filler. Different (organic or mineral) cementing compounds or mortars can be used for this. Where necessary, connections and joints are sealed with permanently elastic material or with special water stops.

Windows must also be installed with care. To ensure that the window sits tightly, the window installer fills the hollow voids between the window frames and masonry with foam. Joints between the window frames and masonry are sealed with permanently elastic joint sealing compounds.

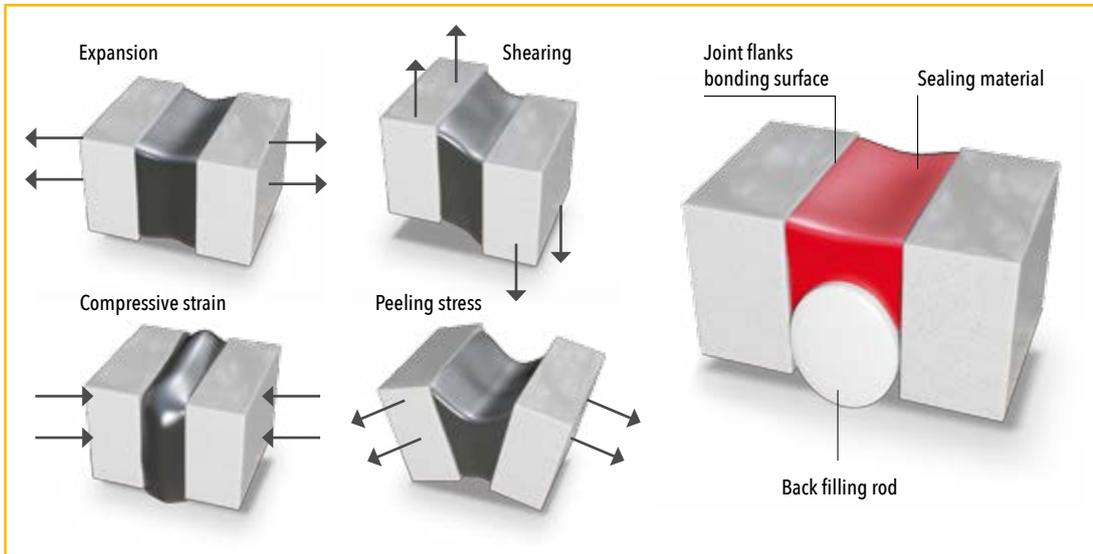
>> [Mortars 4.2; Mortars for Joints and Laying Tiles 4.2.1; Floor Levelling Compounds 4.2.3; Renders and Adhesive Mortars 4.2.4; Reactive Resins 4.3.1](#)

#### ILLUSTRATION 4

Schematic diagram of layer construction



Loads on joint sealants



Joints are deformed differently, depending on the building element and the forces that act on them (left). The sealant must be permanently elastic. A back filling rod is placed in open joints first (right) to prevent the injected joint sealant from running down into the joint. An elastic joint sealant is then applied.

● Kitchen and Bath

The tile layer waterproofs the carcass walls and the floor in the bath and in other wet areas first. Then he cements tiles to the wall. Depending on the substrate, a rigid or an elastic mortar is used.

The joints between the tiles are tightly closed with joint mortars that are not elastic. Joints between the bath tub, shower and wall are sealed with permanently elastic materials because in these areas different materials are joined that deform differently when temperatures change. A joint that was not sealed with an elastic material would tear.

Not only joint mortars but also permanently elastic joint sealants come in different colours that can be coordinated to each other and with the tiles.

>> [Joint Mortars 4.2.1](#); [Waterproofing Grouts 4.2.2](#)

● Balconies and Terraces

The tile layer also waterproofs terraces and balconies. These are especially problematical areas of buildings since the waterproofing connects different building materials to each other and must also adhere well to each of these materials. Waterproofing and covers on terraces and balconies are also subjected to extreme environmental influences such

as heat, UV radiation and frost. To achieve smooth and resistant balcony surfaces, tiles are often used as well as coatings made of synthetic resin.

Tiles and slabs in outdoor areas are cemented with mortars that contain elastic, polymer components. These components prevent the tiles from detaching from the substrate or cracking due to fluctuating temperatures.

>> [Mortars for Joints and Laying Tiles 4.2.1](#); [Reactive Resins 4.3.1](#)

NOTE

**Joint sealants – must always remain tight**

Since the size and relative length of building elements can change when subjected to mechanical loads and especially fluctuating temperatures, the width of the joints between the individual building elements or materials can vary considerably over the course of time. Joint sealants must thus have sufficient and permanent elastic deformation capacity if they are to remain permanently tight. Joint sealants are injectable materials that can be easily applied and are sold in cartridges (silicones, acrylates and polysulfides).



### ● Heating Oil Basements

After the floor and walls in heating oil basements have been levelled, they are coated with a wall render or an oil resistant and oil impermeable polymer coating. If oil should run out when the tank is filled or if the tank should leak someday, no oil can reach the ground and ground water through the floor.

>> *Reactive Resins 4.3.1*

### ● Facades

Facades in particular are what give a building its character. Facades also function as an outer skin to protect the building and can be decorated in many ways. Normally, two layers of an exterior render (an undercoat render and a finishing render) are directly applied to the masonry work. If walls, especially concrete walls, are insulated to save heating costs, a "bonded thermal insulation system" is often installed on the external walls.

This system consists of insulation panels that are cemented to the substrate with adhesives and anchored with plastic dowels. The entire surface is then coated with a render into which a textile fabric is laid as "reinforcement". The layer of render that has been stabilised in this manner (reinforcement render) prevents the render from cracking or spalling. After this undercoat render has hardened, a finishing render is applied.

The connections to windows, doors and interpenetrations, e.g. for ventilation pipes, must be sealed with great care. Ready-made components made of plastic can be used for this purpose as well as the special mortars and joint sealants already mentioned.

>> *Render and Adhesive Mortars 4.2.4; Building Insulation 4.2.5*

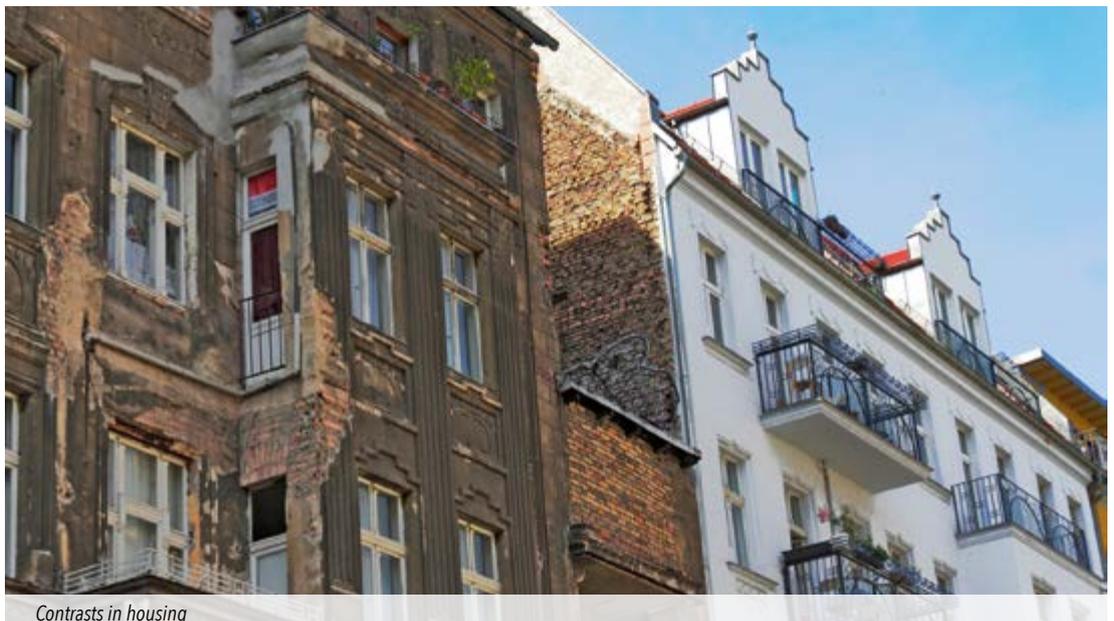
### 3.1.3 Protection and Maintenance

Every house ages over the years and each building material – wood, masonry work or concrete – has its own service life. The durability of a building material or the state of a building also depends on how it is utilised. Office buildings and industrial buildings are subjected to more wear than a weekend house. Location also plays a role in the aging of buildings – whether the building is in the mountains where there is intensive sunlight, the salty air near the ocean or subjected to vibrations caused by earthquakes.

Maintenance and repair work are therefore important if a house is to stay intact for a long time – just like they are for automobiles.

#### NOTE

Repairs and maintenance make up approximately half of the construction work in Europe.  
(Source: Deutsche Bauchemie e. V.)



*Contrasts in housing*

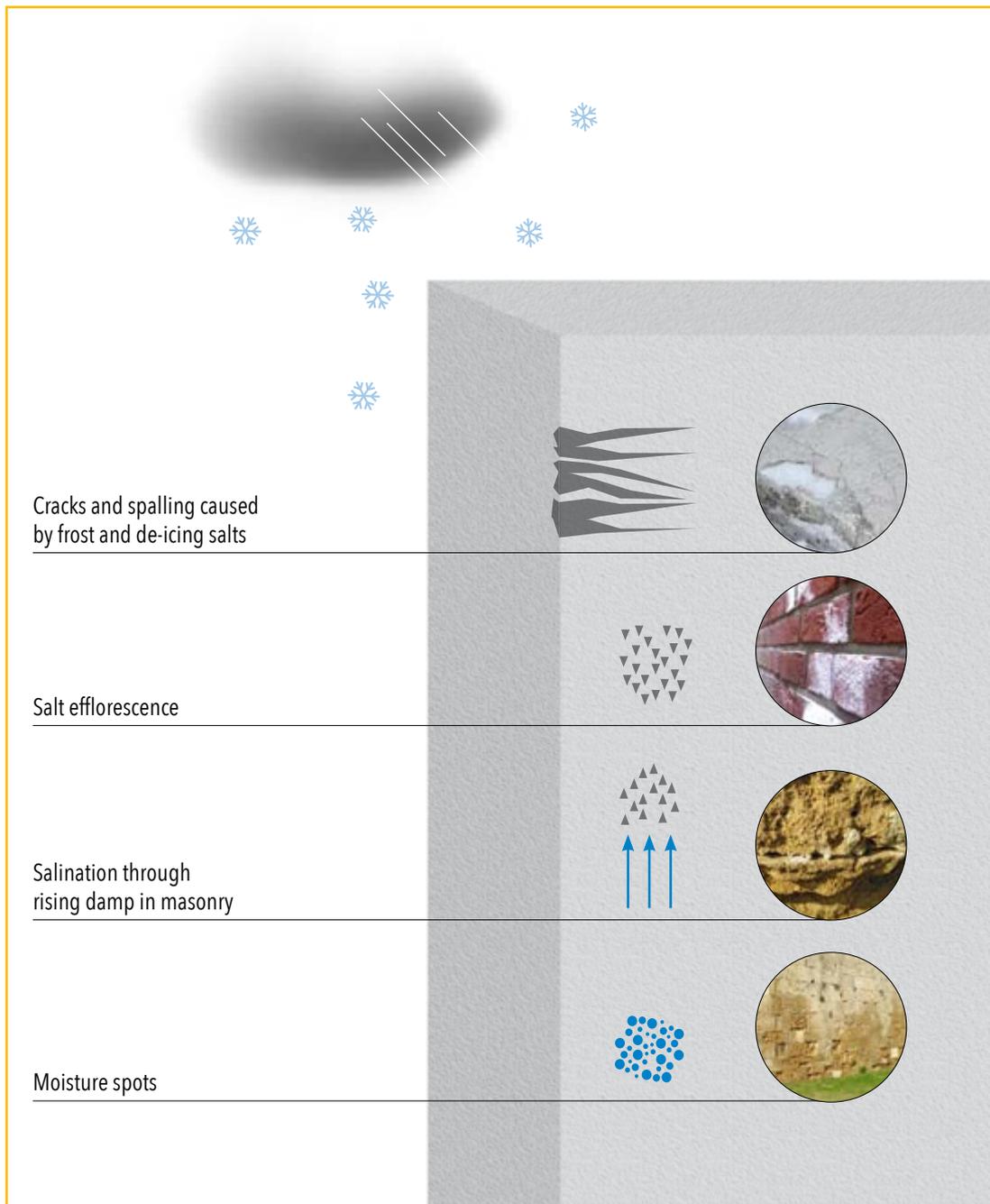
● **Damp Building Elements**

It starts with being wet: Damage to buildings begins very simply with water. Water penetrates into the building and transports dissolved, harmful substances through the capillary system of mineral, porous building materials. The ravages of time gnaw on all buildings that are exposed

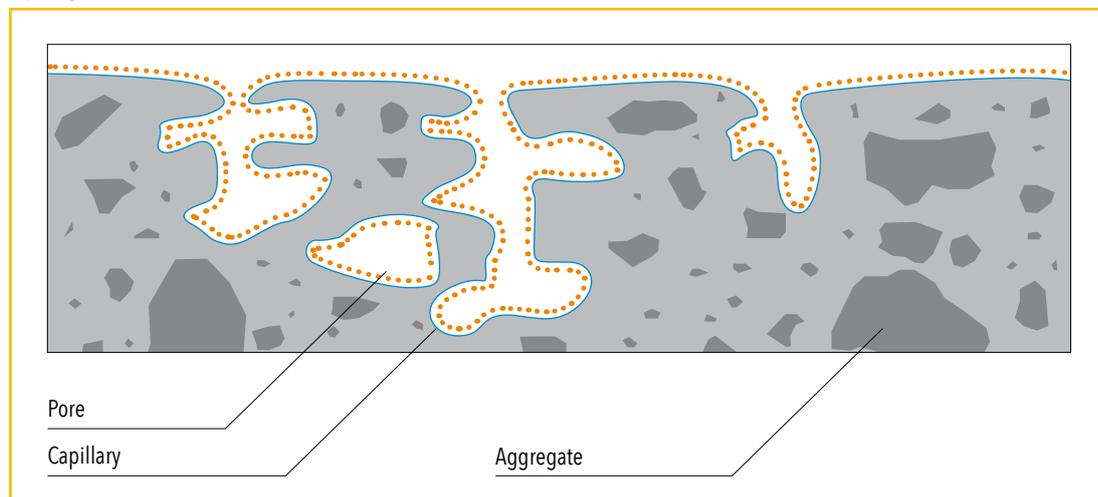
to weather. Water makes walls damp, rises in masonry work, causes cracks to form and leaches out the building material. It penetrates into concrete roads that have been damaged by frost and de-icing salts or it destroys concrete through corrosion of the steel that is embedded in the concrete.

ILLUSTRATION 6

**Damage caused by moisture**



Hydrophobization (schematic)



To ensure that water cannot cause damage to a building material for a long period of time, the building material can be treated to make it water repelling (hydrophobic). The hydrophobizing agent simply repels rain from masonry work, mortar or concrete.

Hydrophobizing agents line the internal walls of pores and capillaries in the building material and prevent moisture from entering. This also prevents damage caused by frost and corrosion as well as the efflorescence of salts and leaching of lime. And, where there is no moisture, algae, mildew and moss cannot grow. Since the pores and capillaries of the respective building material are not closed off by the hydrophobizing agent, the mortar and masonry

work still remains capable of "breathing", i.e. the diffusion capacity of the building material is maintained.

Over the course of time, the hydrophobizing effect diminishes, allowing moisture to enter the outer skin of the building. To reinstate the hydrophobizing effect, either a coat of paint with a hydrophobizing effect can be applied or the hydrophobizing agent can be applied again. Today, silicones and silicone related products on a silicon base such as silanes\* and siloxanes\* are mainly used for water repelling impregnation of mineral building materials.

>> *Silanes, Siloxanes, Silicones 4.4*



Hydrophobized concrete surface

TEACHER INFORMATION

- Experiment VI: Hydrophobization of building materials
- Experiment VIII: Self-cleaning surfaces
- Experiment IX: Restoration render in a model experiment
- Worksheet 12: Salt-loaded walls – use of restoration render

### ● Salt-Loaded Walls

One problem that goes hand in hand with moisture is the salination of masonry work. In the case of poorly waterproofed old buildings, moisture penetrates from the outside into the walls and transports salts through the masonry right to the surface of the interior walls. If the salts crystallise, large parts of the render spall. Actually, there is a relatively simple solution for such destructive problems: Restoration render. Restoration render is used because of its limited ability to conduct moisture. Since it does not conduct moisture well, the water that transports the salt from the masonry work cannot reach the surface of the wall. It evaporates at the render base through the pores. The dissolved salts crystallise and remain in the pore space of the layer of render. Depending on the degree of salination in the masonry and the effectiveness of evaporation, the pores fill more or less quickly with salts until it becomes necessary to renew the render. In principle, a conventional restoration render is a render that has the ability to store salts because of its pore geometry and

prevent them from reaching the surface. The task of restoration renders, which are special premixed mortars, is to ensure a dry and damage-free render surface on damp masonry with salt loads. It cannot, however, waterproof the masonry work.

>> [Repair Mortars 4.2.6](#)

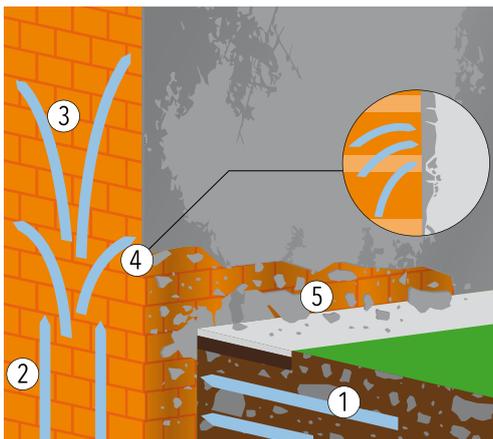


Damaged wall caused by salt

### ILLUSTRATION 8

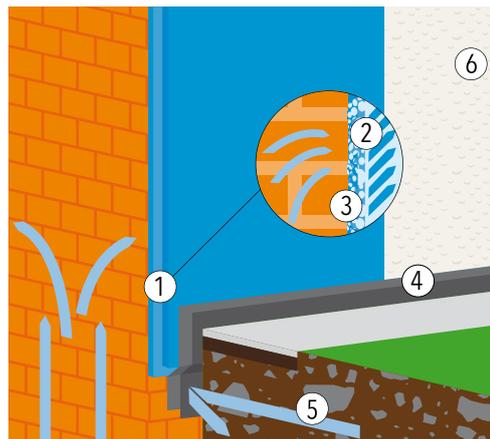
#### Water and salt in masonry work – a chronology of disintegration

##### Damage mechanism



1. Water penetrates into the masonry work
2. There is no horizontal barrier or it is defective
3. Water and salts rise in the masonry work
4. The render and coating are damaged and fall off
5. The masonry work disintegrates

##### Repair of the damage



1. Restoration render is applied
2. Moisture can easily and quickly evaporate through the pore structure
3. Salts crystallise in the pores without causing damage
4. Subsequent waterproofing
5. Damp zone is lowered
6. The render and coating remain dry and undamaged

### 3.2 Construction Chemical Products for Special Applications: Television Towers, Bridges, Tunnels and Co.

One of the most important tasks of construction chemical products is to give different building materials entirely new or improved properties: industrial floors, for example, become more hard-wearing, graffiti can be more easily removed from house walls, and concrete remains workable longer or sets more quickly.

#### ● Concrete Buildings with Heavy Loads: Civil Engineering Structures

As a rule, retaining walls and structures in road construction or in hydraulic engineering must be able to withstand much heavier loads than a classic, single family house. Construction chemical concrete admixtures are essential in these cases. Concrete used for tunnel construction, for example, must react and also harden especially quickly so that the tunnel does not collapse and the construction team is protected from falling rocks when tunnelling. In this case, an accelerator is added to the concrete which is sprayed against the rock (sprayed concrete) with appropriate machines where it hardens in just seconds.

Concrete used in road construction must be resistant to frost and de-icing agents. It must also defy ice because if ice forms in the concrete, the enormous pressure that is created by expansion damages the concrete structure and the surface of the concrete spalls. For these cases, air entraining agents are added to produce additional pores in the concrete which provide room for the expansion of freezing and expanding water. They make a service life of more than 30 years possible for concrete roads today.

Concretes used for bridges, television towers and other civil engineering structures are also subjected to extremely heavy loads. In these cases, only special concretes with high strength can be used. Since these concretes must also be easily workable because they must be pumped to great heights (television towers, cooling towers in power plants), plasticizers and superplasticizers are added, for example. These allow the production of flowing concretes and self-compacting concretes. High strength concretes can be produced, the strength of which nearly matches that of steel.

>> [Concrete 4.1; Concrete Admixtures: 4.1.1](#)

#### NOTE

About 90 percent of the concrete produced in Germany contain additives.



Salginatobel Bridge



Sunniberg Bridge



Artes, Valencia

● **Protecting and Waterproofing Civil Engineering Structures**

Large infrastructure projects such as bridges, skyscrapers but also clarification plants must last for decades. A prerequisite for this is that they are protected from the ingress of liquids, from abrasion through traffic or chemical attack through aggressive liquids. Polymers are used in many cases for this purpose.

Highway bridges made of concrete, for example, are coated with several layers of different coating materials before the final asphalt pavement is placed. To prevent chlorides in de-icing salts from migrating down to the steel in concrete, which would cause corrosion, the concrete is coated with a layer of resistant reactive resin\* such as polyurethane and additionally with bitumen waterproofing sheets. Reactive resins can also be used for chemical resistant coatings in clarification plants, tanks for chemicals or oil tanks. In these cases, it is important to prevent liquids hazardous to the environment from seeping into the ground or ground water. And, of course, the concrete itself must be protected from attack by chemicals.

Coatings for swimming pools must remain impermeable for many years. Resins are used here that exactly adapt to the geometry of the pool when applied. These resins must also be able to withstand chlorine, disinfectants and sun oils in the water as well as intensive UV radiation in summer.

>> [Reactive Resins 4.3.1](#)

● **Reinforcing Civil Engineering Structures**

When a bridge ages, cracks in the concrete become visible and at the same time more automobiles and lorries thun-



Television tower in Stuttgart, Germany

der across it every day than were ever expected. When a bridge reaches the limits of its planned service capacity because of this, its load-bearing capacity must be reinforced. CFRP laminates (CFRP = carbon fibre reinforced polymer) may be the therapy of choice in this case. They are cemented on the outside of the concrete in the form of flat, polymer fibre bands or, for large surfaces, in the form of CFRP fabric mats which act like a support corset. This relieves the heavily loaded concrete. CFRP laminates are also used on other concrete structures such as towers with a similar effect.

Such subsequent reinforcement with CFRP laminates is not only used when loads have increased but also when the load-bearing capacity of a structure has been jeopardised, for example, by a fire.



Swimming pool waterproofing

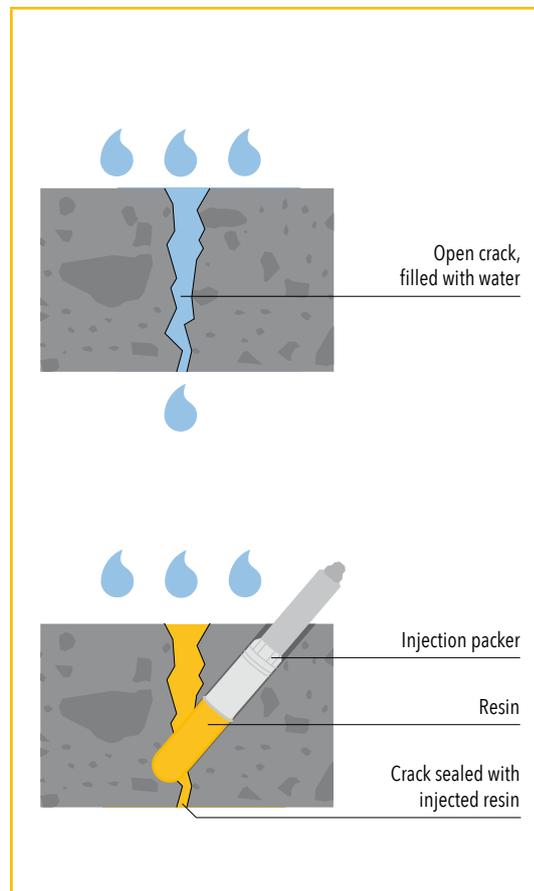
### ● Closing Cracks: Crack Injection

Cracks in buildings are unavoidable. In the case of reinforced concrete the expression “cracked construction” is even used. Cracks appear in different widths. Some cracks, especially small cracks, can close again all by themselves; experts then say “the concrete has healed itself”. This can happen, for example, through subsequent hydration of cement that has not yet reacted, through the formation of lime (carbonation) or because hydrated cement in the concrete swells. Larger cracks, on the other hand, often endanger the load-bearing capacity and durability of a structure and must thus be closed. Cement paste or cement suspensions\* can be used but in most cases reactive resins are employed.

>> [Reactive Resins 4.3.1](#)

#### ILLUSTRATION 9

##### Crack injection



#### FIGHTING CRACKS – WITH CRACK FILLING MATERIALS

Even in a building that has been constructed according to all the rules of the art, the so-called “Generally Accepted Rules of Engineering”, cracks may form – for example through movements and settlement in the ground. But even that is not a real problem because along with mineral, relatively brittle cement pastes and cement suspensions, polymer, permanently elastic systems such as polyurethane or epoxy resins are very suitable for filling cracks in older buildings. Experts call these filling materials. Resins are actually ideal fillers for voids. They are so liquid that they penetrate even into the smallest, almost invisible scratches of only approx. 0.1 millimetre. The smallest measure on a set square is one millimetre. Resins fill cracks that are ten times narrower!

The cement products are a little thicker and are only suitable for cracks at least 0.8 mm wide – but still. If you have ever tried to fill a large quantity of liquid into a small opening – like water in the hole of a squirt gun, for example – you know that a lot of the water runs past the hole. That would not be very professional, of course, when repairing concrete, so in these cases, so-called packers are used – thumb-thick filling tubes that are screwed into the cracked wall (drill packer) or are cemented on the crack (adhesive packers). With the aid of an electric injection pump, the filling material is injected into the wall through the packer. Cement suspensions are injected into walls with a pressure of approx. 10 bar – three times the pressure in a bicycle inner tube. The problem with this: If the pressure is increased, the filling material on a cement base separates into its aggregate groups – the large grains sit tight and the packer becomes clogged. Resins, on the other hand, can be injected with up to 100 bar pressure. That is the pressure that predominates at a water depth of 1,000 metres! Every ever so small void is filled.

#### NOTE:

Intensive research and development have produced the nearly 40,000 different construction chemical products we have today and each year more than 100 new developments are added. Thanks to continuous development, an increasing number of highly sophisticated, special structures can be built and permanently protected.

Innovative construction chemical products also make a large contribution in increasing the service life of buildings. Surface protection systems as well as waterproofing and coating materials protect buildings from environmental influences and decay. Repair systems also facilitate restoration and make buildings resistant for decades.



#### ● Floor Coatings

Floors are certainly among the surfaces that are subjected to the heaviest loads – especially industrial floors – but also floors in sport facilities. Industrial floors must be abrasion resistant, even when heavy forklifts continuously drive back and forth. They must also be able to withstand strong cleaning agents or aggressive chemicals. Floors in sport halls should remain beautiful for many years, even with continuous abrasion caused by rubber soles. Heavy sport equipment is rolled over the floors and when school celebrations are held, tables and benches are pushed here and there. Only an extremely durable cover can withstand such loads. The different reactive resins are ideal coatings. Depending on application, the floors can be constructed like a sandwich to lend them different properties. In industrial areas, wires can even be laid beneath the epoxy resin to lead off electro-static charges. This is important, for example, when sensitive computer chips and other electronic components are produced that could be destroyed by tiny charges, but also when working in surroundings at risk of explosion.

>> [Reactive Resins: 4.3.1.](#)

#### 📌 TEACHER INFORMATION

Worksheet 11: Graffiti, a field of conflict



#### ● Anti-Graffiti Coatings

Graffiti: For some it is art but for most house owners it is a real nuisance because the lacquer cannot be easily removed from render or wall paint. It has to be removed mechanically by scrubbing, high pressure cleaning or stripped with solvent based chemicals. This is very time consuming and expensive. But today there are construction chemical agents for protection – anti-graffiti coatings on a siloxane/silane\* base. All you need to do to protect the wall is to coat it with an invisible anti-graffiti coating. Not only water repelling but also oil repelling molecules project from the coating. Practically no lacquer can adhere to such a coating, neither a water based nor a solvent based lacquer. Normally, a strong blast of water is all you need to remove the unwanted painting. Such an anti-graffiti coating cannot prevent new graffiti but it can at least be easily removed because the lacquer used for the graffiti no longer adheres tightly.

>> [Silanes, Siloxanes, Silicone 4.4](#)



Graffiti – art or a nuisance?

#### 4.1 Concrete: It All Comes Down to the Mixture

Concrete used to have a bad reputation: Cheap, dreary and crumbling in the end; those were the prejudices. But thanks to modern construction chemical admixtures, the grey mass has blossomed into an extremely variable, high-performance building material. Concrete can be rigid or elastic. It can be grey, white or coloured as well as smooth or textured. It can even swim and allow light to pass through. Anyone who builds a house of his own knows: There is no way around concrete. Experts have long called it the building material of the century.

After mixing, the fresh concrete is filled into a mould (formwork). Through the reaction of the cement with water, the fresh concrete hardens to solid concrete. The formwork is removed after hardening and can be reused. Hardened concrete has high compressive strength but approximately 20-times less tensile strength. To absorb the tensile forces in the building, the concrete is reinforced with steel since steel has high tensile strength and is also permanently protected from corrosion in the concrete. Steel reinforced concrete, simply called "reinforced concrete", is a composite material made of steel and concrete.

Concrete properties, for example consistence, compressive strength and durability, are decisively influenced by the ratio of water to cement, the so-called water/cement ratio (w/c ratio). The properties of concrete can be optimised by reducing the water/cement ratio. But there are limits to this reduction. The less water you add to the concrete mixture, the stiffer it becomes until it is no longer workable.

If the content of water and cement is increased at the same time without changing the water/cement ratio, the cement content related to a specified volume of concrete (for example a cubic metre) would at some point be so high that undesired properties would occur, for example strong shrinkage, i.e. a shortening in length while drying and, in conjunction with this, a clear increase in the number of cracks. This is where concrete admixtures such as plasticizers and super plasticizers help. They give concrete with a low w/c ratio, i.e. made with less water, excellent working properties. Without these special concretes, the construction of skyscrapers such as the Burj Khalifa, in which the concrete had to be pumped upward several hundred metres, would not be possible.

#### NOTE

##### Water/cement ratio

The water/cement ratio is the decisive criterion for the properties of not only fresh concrete but also hardened concrete, for example workability, compressive strength and durability.

$$w/c = (\text{mass of water})/(\text{mass of cement})$$

With 140 l = 140 kg water and 280 kg cement you have a water/cement ratio of 0.5 which corresponds to 140/280. With the same quantity of water and 350 kg cement, the water/cement ratio is reduced to 0.4 corresponding to 140/350.

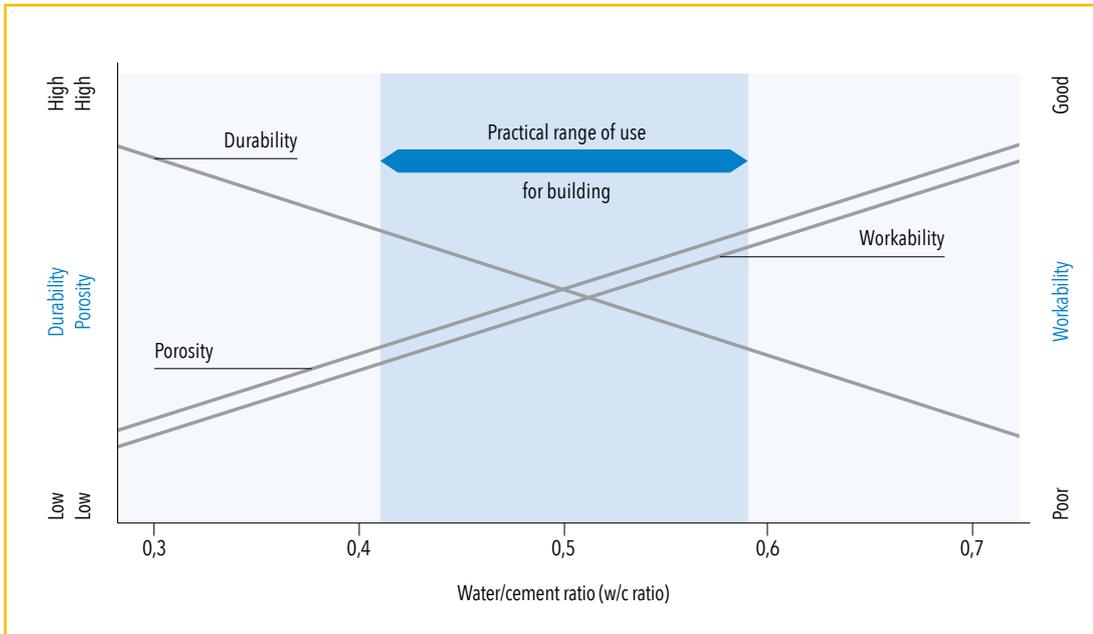
Even though both concretes have a comparable consistence and workability, they differ in regard to their hardened concrete properties such as compressive strength and durability. With a water/cement ratio of approximately 0.4, the entire quantity of water added is bonded chemically and physically by the cement. Any additionally added water evaporates during and after hardening and leaves pores in the structure. These pores reduce the strength of the concrete since pores cannot transfer any forces. Furthermore, the pores drastically reduce the durability of the concrete. Harmful substances such as gasses and dissolved salts can penetrate into the concrete structure through these weak places.

With a decreasing water/cement ratio, the consistence of the fresh concrete becomes increasingly stiffer and less workable. To make concrete more workable without adding more water, special concrete admixtures, superplasticizers, are used. To ensure the required quality of ready-mixed concrete, the subsequent addition of water to improve workability is always strictly prohibited.



Concrete canoe

Qualitative dependency of porosity, durability and workability of concrete on the water/cement ratio



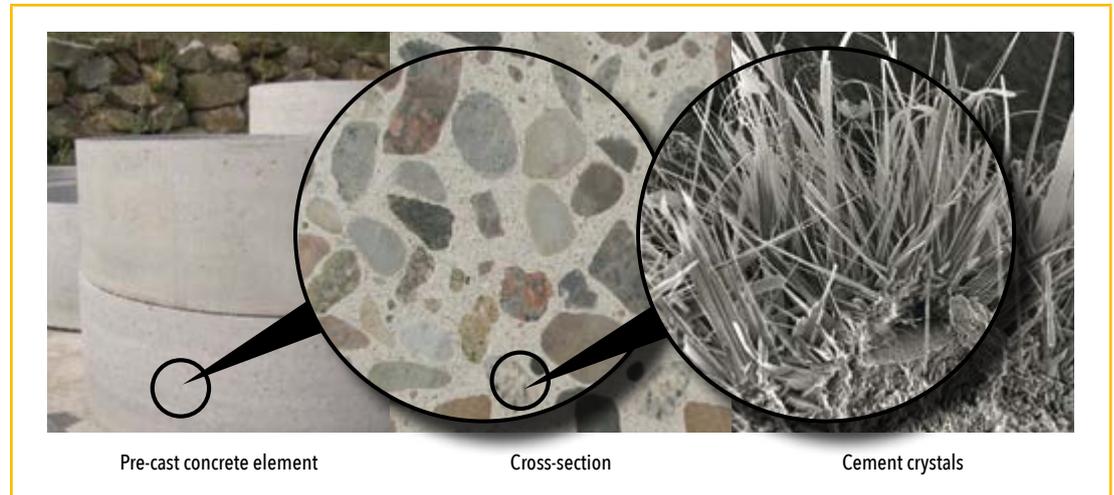
Cement begins to stiffen and harden after a certain time (~2 hours) – and even earlier at high temperatures. This must be taken into consideration, especially in the case of ready-mixed concrete that is delivered to the construction site in a truck mixer. Since the quality of concrete that is mixed in a concrete plant is more uniform and therefore better than concrete produced at the construction site, retarders are added at the mixed concrete plant today to make the concrete workable for a longer period of time, e.g. when driving times are longer, there will be waiting times at the construction site or working times are longer.

Therefore, concrete is not just concrete: The construction chemical industry has turned the classic three-component system consisting of cement, water and aggregates into a highly flexible, six-component system. This refers to additives (substances in liquid or powder form such as powdered minerals, cinder sand or fly ash), which can be added to the concrete in larger quantities, and admixtures (organic and inorganic substances such as superplasticizers, accelerators, retarders or air entraining agents), which are usually added to concrete in liquid form and in small quantities. The sixth component is air. Through selective control of air pores, concretes can be made either frost resistant or extremely impermeable against the penetration of aggressive substances that damage concrete (see Illustration 13).



Concrete mixing truck while unloading concrete

A look inside concrete



● Cement – an Adhesive

Without cement there would be no concrete. Cement is the most important binder for this building material. To produce cement, the raw materials limestone, clay and sand are excavated in quarries and mines, crushed and transported to cement plants. There they are finely ground and heated in enormous rotary kilns which can be more than 100 metres long to 1,400 to 1,500 °C. The calcium carbonate ( $\text{CaCO}_3$ ) is burned to calcium oxide ( $\text{CaO}$ ) which then combines with the silicon oxide ( $\text{SiO}_2$ ) from the sand and the aluminium oxide ( $\text{Al}_2\text{O}_3$ ) from the clay to become so-called cement clinker. The burned raw materials usually also contain iron oxides ( $\text{Fe}_2\text{O}_3$ ) which also become a part of the cement clinker. The cement clinker is an intermediate product and does not set by itself but if you grind it to powder, its reactive surface is so large that it reacts with water very quickly – too quickly for mortars and concretes. Working time would be too short. To reduce the speed of the reaction, gypsum or natural gypsum in the form of anhydrites\* is added to the pulverised clinker. The mineral mixture absorbs the water and forms long, fibre-like crystals that mesh together to form a solid mass. Mineralogists call the insertion of water molecules in crystals hydration and binders that set in this manner are called hydraulic. Cements are thus hydraulic binders\*. The resulting meshed mass, so-called hydrated cement, is no longer soluble in water and cements all of the aggregate components together, right up to the largest pebble. The result is hardened concrete.

4.1.1 Versatile Concrete – Thanks to Admixtures

More than 90 percent of all concretes today contain chemical admixtures that are mixed with the initial product consisting of the binder cement, water and aggregates.

But what exactly is the secret behind these products that make concrete durable, economical and versatile? And how do they act? In the case of concrete and ready-mixed concrete, liquid substances are usually used that consist of organic and inorganic substances. These are mixed into the cement in such small quantities that there is no change in the weight of the concrete. But their actions are all the more impressive. Admixtures influence the properties of fresh concrete as well as hardened concrete by chemical as well as physical means.



- Always Flowing: Plasticizers and Superplasticizers**  
 Concrete plasticizers are found in practically every concrete. On the one hand they ensure that the concrete is easier to work and can be worked longer without having to add additional water. On the other hand, they can reduce the quantity of water required for mixing the concrete – at least 5 to 10 percent or even more. That increases the strength of the concrete: It has the same workability but is denser and more resistant.

Plasticizers can reduce the surface tension of water, for example, which allows the solids in concrete to be wet more easily. Plasticizers also allow the cement to be completely and finely distributed (dispersed) which reduces friction between the solids and results in greater mobility and thus better workability of the concrete. With the aid of a plasticizer, especially polycarboxylether\*, the concrete flows by itself and comes to rest so densely that it no longer needs to be compacted by vibrating (self-compacting concrete).

- Foam against Ice: Air Entraining Agents**  
 Air entraining agents are essential, for example, when roads must be made frost resistant. Air entraining agents are surfactants and thus in the same substance class as cleaning agents. They reduce the surface tension of water and allow tiny, stable air bubbles to form just like foam from soap. The use of air entraining agents when mixing concrete increases the formation of air bubbles which form pores when the concrete hardens. This additional pore space provides sufficient space for freezing water. Without these pores, the pressure that results from the expanding ice crystals would cause the structure to burst and the surface of the concrete would spall.

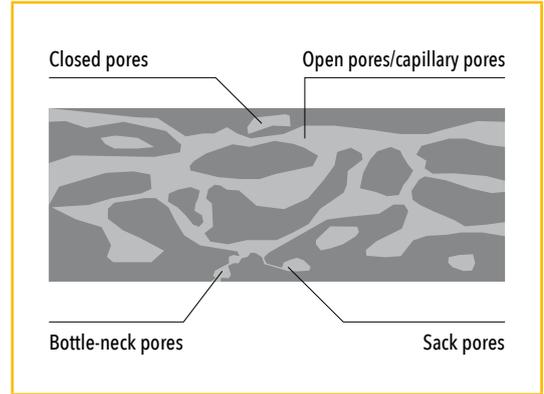
Air entraining agents are either made of natural resins or synthetic surfactants.

- Nice and Slow: Retarders**  
 When temperatures are high outdoors and hydration of the cement is accelerated or if routes for delivering ready-mixed concrete are long and the working time of the concrete is no longer sufficient, it is necessary to increase the working time of the concrete and inhibit hydration of the cement. This can be achieved by so-called retarders. The time can actually be delayed from several hours to several days. From a chemical standpoint, these admixtures tem-

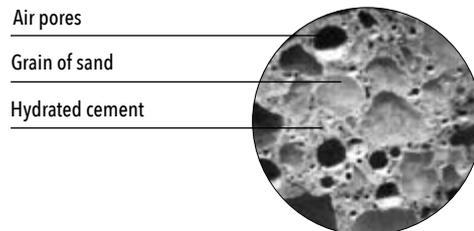
porarily prevent the initially reacting cement constituents from dissolving and thus delay the begin of hydration.

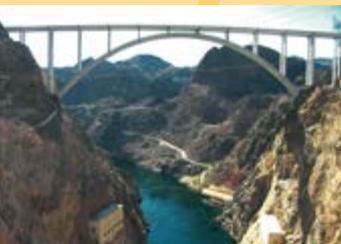
**ILLUSTRATION 12**

**Types of pores in concrete**



As soon as hydration sets in, strong heat is created by the chemical reaction which can cause a concrete building element to become very warm. In this case, retarders help by extending the reaction time which dampens the strong development of heat. This is important especially for massive structures, e.g. when placing concrete for dams, locks or thick foundations and floor slabs for high-rise buildings. An effort is made to reduce temperature peaks and keep hydration temperatures low by adding a retarder, by cooling the fresh concrete in the mixer with ice and cooling the placed concrete with the aid of cooling pipes through which cold water is pumped. Otherwise, cracks would form due to the great difference in temperature between the outside and the core while cooling and the required impermeability of the structure could no longer be guaranteed.





Hoover Damm, USA

When the Hoover dam was built in the USA, for example, it would have taken 100 years for the concrete in the core to finally cool without the aid of cooling pipes. Thanks to cooling pipes, this was achieved in two years. With the dams built today, this only takes half a year to one year because of the chemical admixtures and special cements with low hydration heat that are used.

The most conventional and most effective retarders are produced on a gluconate and sucrose base – and are therefore sugar derivatives. Even better are retarders on a phosphate base which are mostly used for ready-mixed concrete today.

- **When in a Hurry: Accelerators**

When construction needs to be completed quickly, accelerators are used. This is the case in tunnel construction where the concrete must become strong extremely quickly. But also when there is sudden water inrush in a tunnel or when constructing sewers, accelerators are the admixture of choice. Just opposite retarders, accelerators cause the cement components to go into solution more quickly. The cement reacts in just seconds and develops strength.

- **For Clean Separation: Concrete Release Agents**

Concrete is poured into a mould at the construction site that is called formwork. This formwork is made of wood or plastic panels which are joined together in such a manner that the desired concrete element is produced – a support, wall or ceiling, for example. Especially when the concrete will be visible on the finished building (fair-faced concrete), the surface of the concrete must satisfy special

requirements regarding appearance. In this case, it is important that the concrete can be cleanly separated from the formwork after it has hardened. To ensure this, the formwork is pre-treated with different concrete release agents, depending on the material of the respective formwork. These substances prevent the concrete from adhering to the formwork panels or even penetrating into the surface in the case of absorbent formwork. In some cases, formwork is used as a type of negative mould which leaves a knothole or wood grain look on the hardened concrete. Effects like these or surfaces with other patterns can be produced with high performance concrete release agents. As a rule, water based emulsions are used for absorbent formwork which may be based on renewable raw materials such as palm fat or palm oils. Solvent-free release agents on a mineral oil base are used on non-absorbent formwork.

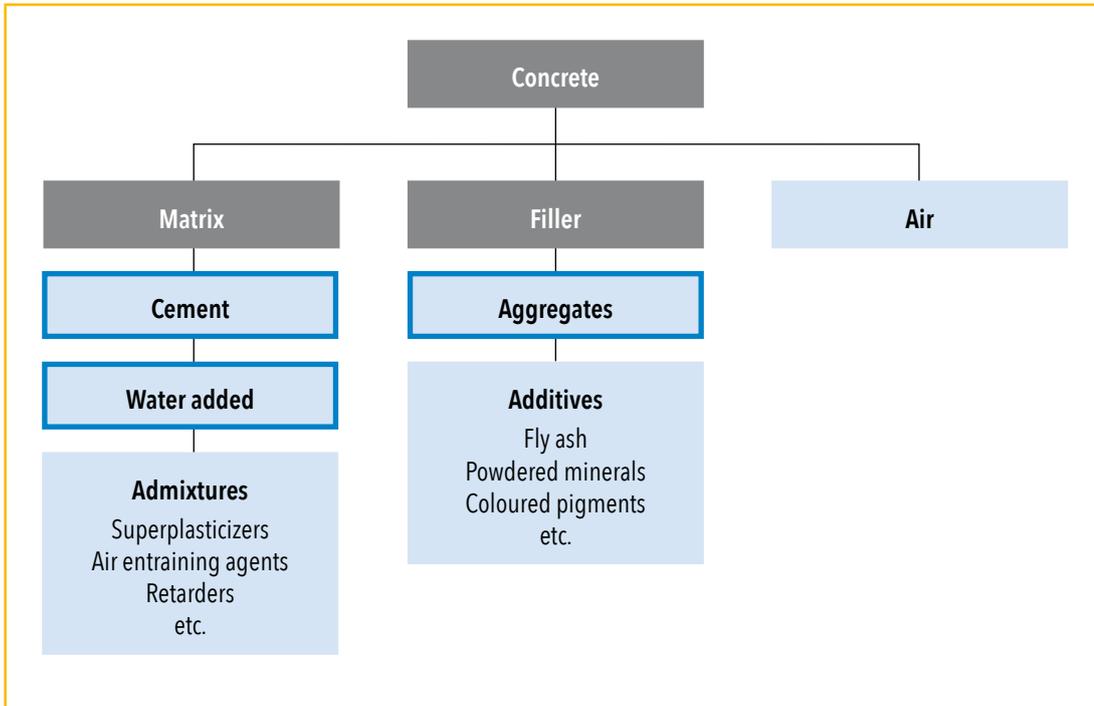
- **Preventing Cracks: Concrete Curing Agents**

The construction of large-surface structures such as concrete roads or large floors/intermediate floors is problematical because water can easily evaporate from large surfaces of concrete before it has properly set. As a consequence, the concrete dries out and cracks form in which water can easily penetrate. To retard evaporation, the surface of the fresh concrete is treated by spraying a paraffin wax dispersion over the fresh concrete. The paraffin particles, which are finely distributed in an aqueous dispersion, form a uniform film on the surface of the concrete after drying which prevents further evaporation of water from the concrete and thus drying. This considerably improves the quality of the concrete surface.

Pantano del Montoro, Spain



The composition of classic and modern cement



Concrete is generally composed of a matrix with an enclosed filler. Classic concretes are three-component systems (boxes with the dark blue frames); modern concretes consist of six components (boxes with light blue backgrounds)

Concretes consist of a binder matrix and a filler

TYPE OF CONCRETE	BINDER MATRIX	FILLER
Normal concrete	Hydrated cement	Aggregates
Light-weight concrete	Hydrated cement	Expanded clay/tuff
Antique "Roman" concrete	Limestone	Crushed masonry stone
Heavy-weight concrete	Hydrated cement	Steel pellets
Asphalt concrete	Bitumen	Aggregates
Insulating concrete	Hydrated cement	Styrofoam balls

TABLE 1

Raw materials for concrete admixtures and indirect materials

Type of admixture	Raw materials
Concrete plasticizers	Lignosulphonates and, in some cases, additions of melamine sulphonates and naphthalene sulphonates and/or polycarboxylates
Superplasticizers	Melamine sulphonates and naphthalene sulphonates and/or polycarboxylates, in some cases the addition of lignosulphonates
Air entraining agents	Soaps made from natural resins as well as synthetic, ionic and non-ionic surfactants
Retarders	Sucrose, gluconates, phosphates, lignosulphonates, zincates
Accelerators	Silicates, aluminates, carbonates, formates (salts of formic acid), aluminium sulphate, chlorides
Concrete release agents	Aqueous emulsions, solvent-free release agents on a mineral oil base
Concrete curing agents	Aqueous paraffin dispersion

● Cracks and Damaged Concrete

As a rule, water cannot harm a concrete building that is intact, especially when it has been built with water impermeable concrete. But in spite of even the most thorough planning of construction works and first class workmanship, it is possible for cracks to appear after a while in concrete structures – for example because the soil beneath the structure has settled (settlement cracks), because the building has been subjected to vibrations caused by traffic or earthquakes (movement cracks), because increasing numbers of heavy lorries cross bridges (loading cracks) or because water that contains chlorides, e.g. water contaminated with de-icing salts or sea water, has penetrated the concrete. Water can also damage the reinforcement through corrosion, even when it is several centimetres beneath the surface because chloride ions can migrate deeply into the building material. Sometimes the cracks are so small that they are hardly visible to the naked eye and are only noticed when dark stains or rusty, leaking areas appear on tunnel walls, parking garage walls or the bottoms of balconies. But then it is obvious: Something is wrong here.

NOTE

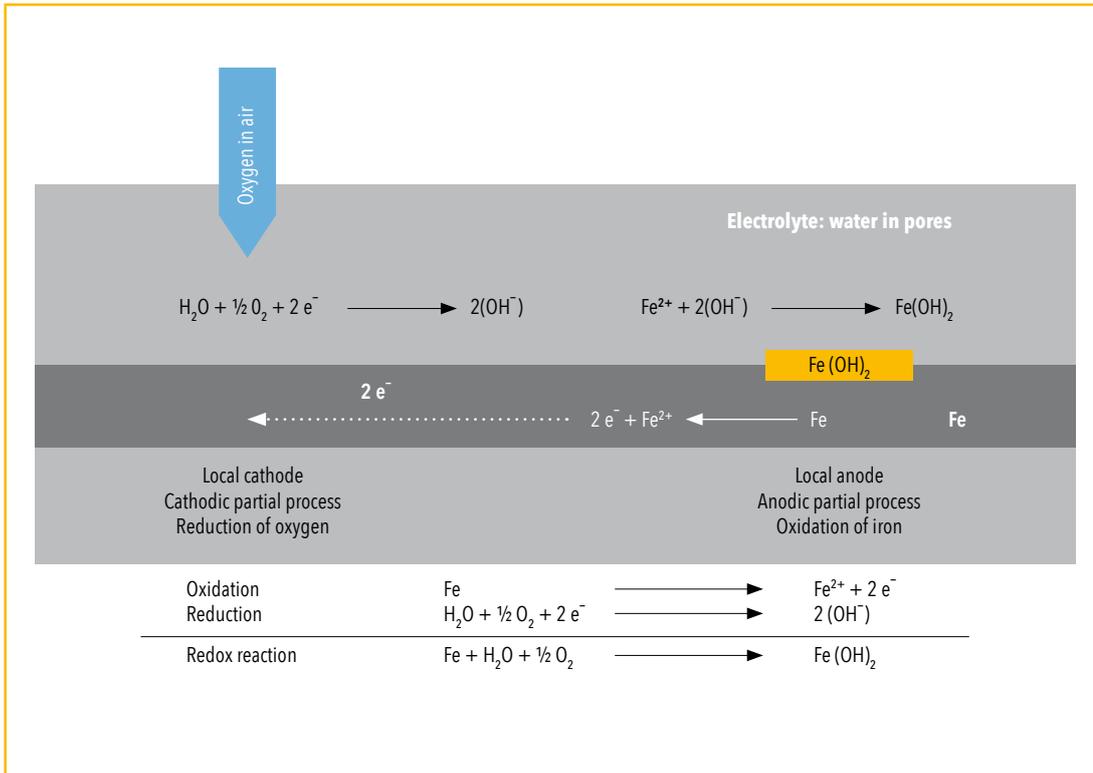
**Corrosion of reinforcement steel**

In buildings that are intact, the alkaline environment of the surrounding concrete protects the reinforcement from corrosion. But environmental influences and cracks in the concrete can cancel this protection. If the diol\* in the hydrated cement becomes carbonated\* by carbon dioxide from the atmosphere, the pH value falls, protection of the reinforcement steel is no longer given and the steel corrodes.



Corroded steel reinforcement

Reinforcement corrosion



REPAIRING BRIDGES

In Germany's federal trunk road network (Autobahns and federal roads) there are approximately 38,000 bridges equivalent to an area of approximately 28 million square metres. Their total length is 1,913 kilometres or twice the distance from Flensburg in northern Germany to Munich in southern Germany. The number of road bridges is even estimated at 120,000 (NRW Road Construction Report). They represent macro-economic assets of approximately 80 billion Euro. To preserve these structures, they must be maintained and repaired. Since traffic continues to increase, these

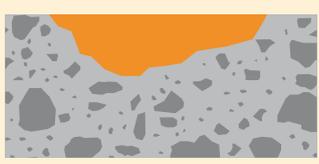
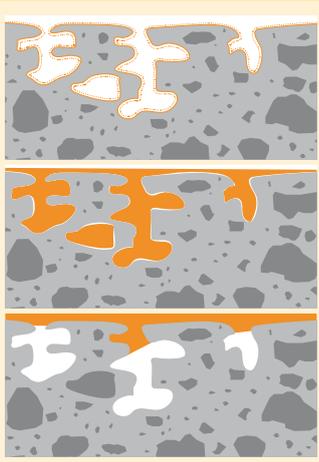
bridges are subjected to increasing loads. As outdoor structures they are also highly exposed to weather. To ensure that these bridges can continue to safely bear passenger traffic and the transport of goods, their load-bearing capacity is often improved with the aid of additionally attached reinforcement (steel or carbon fibre reinforced polymers) encased in a layer of concrete that is sprayed on. Concrete carriageways are often renewed with high-strength concrete which clearly increases the useful service life of such structures.



Bridge construction works

TABLE 2

Concrete restoration is many-sided. According to experts there are different ways to achieve "healthy concrete"

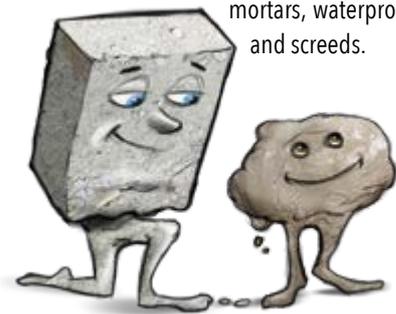
1.	Filling cracks and voids with reactive resin, cement paste, cement suspension	
2.	Filling smaller damaged areas with repair mortar and concrete	
3.	Large-surface application of mortar or concrete	
4.	<p>Application of:</p> <p>a) Hydrophobization agents: impregnation of the concrete to produce a water repelling surface. Pores and capillaries are not filled but lined with the agent and no film forms. The appearance of the surface of the concrete is not changed.</p> <p>b) Impregnation: treatment that seals the concrete to reduce surface porosity. The pores and capillaries are mostly filled. An uneven, thin film forms on the surface of the concrete.</p> <p>c) Coating: treatment that forms a layer to produce a closed, protective layer on the surface of the concrete.</p>	
5.	<p>Reinstatement of corrosion protection for steel reinforcement by</p> <ul style="list-style-type: none"> <li>- Superficial application of mortar or concrete</li> <li>- Local repair with concrete or mortar</li> <li>- Limiting water content in the concrete</li> <li>- Coating the reinforcement</li> </ul>	

TEACHER INFORMATION

- Worksheet 3: Raw materials for concrete
- Worksheet 4: Versatile concrete thanks to admixtures
- Worksheet 8: Corrosion of reinforced concrete through carbonation
- Worksheet 9: Corrosion of reinforcement steel through chloride ions
- Experiment II: The effect of admixtures on concrete
- Experiment V: Experimental proof of carbonation

## 4.2 Concrete's Fine Little Brother: Mortar

Mortar joins masonry stones of any type with each other (masonry mortar), protects against external influences (render mortar) or serves as a wearing layer (screed) and is really no different than concrete. The mixture consists of the same raw materials as concrete: a binder (cement, lime or other binder), water and aggregates (sand). But the constituents of the aggregate are considerably smaller than in concrete and in Germany they are limited, as a rule, to four millimetres. Experts distinguish between non-hydraulic mortar (consisting of lime or gypsum, aggregates, water) which only hardens in air, and hydraulic mortar (consisting of cement or highly hydraulic lime, aggregates, water), which also hardens under water. Up until the 1950s, the production of mortar was always the same: a worker at the construction site mixed cement, lime or gypsum as a binder, sand and perhaps other additives one by one and then added water. The development of premixed mortars after World War II was a milestone: the raw materials and construction chemical admixtures are pre-weighed and pre-mixed and only need to be mixed with water at the construction site – a considerable logistics, time and cost saving advantage. In addition, the mixing ratios always remain the same and do not depend on the less exact measurements of a worker. This dry mortar technology is what allowed the use of so-called high performance mortars such as tile cements, joint mortars, waterproofing grouts, renders and screeds.



By the way: If the grain size of the aggregates is further reduced to under one millimetre, this material is no longer called mortar; these are called hydraulic filler compounds or grouts.

### NOTE

Concrete, mortar, filling compounds and grouts all belong to one group of building materials. They only differ by the size of the aggregates.



*Transport of the Emmaus Church*

## MORTAR AERATED WITH FOAM

### A Church Goes on a Journey

Injection foam mortar is a special kind of mortar that is used to close cracks and joints. Buildings can be refurbished and stabilised, voids and cracks filled and the bonding behaviour of all masonry work components improved with this especially light-weight and flowing capable mortar. In September 2007, thanks to injection foam mortar, a whole church was sent on a trip: In six days, the nearly 20 metre high, 14.5 metre long, nearly nine metre wide and around 800 tonne heavy Emmaus Church in Heuersdorf, Germany, was brought to its new location in Borna, a town twelve kilometres away. The transport of the 750 year old church was only possible with the aid of a special mortar, a so-called injection foam mortar. In injection foam mortar, air pores replace a part of the aggregates used in conventional mortars. The most important ingredients are construction chemical admixtures: a foam former on a surfactant or protein hydrolysate base (egg white foam) and a so-called stabiliser that increases the stability of the foam produced. All voids in the masonry work of the church were filled with this mortar by frictional coupling, making the church so stable overall that the building was able to withstand the vibrations that occurred during transport on a special vehicle. The church was consecrated again in Easter 2008. More than 200 objects in Germany – especially heritage buildings – have been stabilised with this special foam mortar.

Today the market offers a great number of special mortars: Some of them contain up to 20 different admixtures and are tailor-made to meet the most different requirements.

Table 3 gives an overview of the most important ingredients in premixed mortars.

TABLE 3

**Ingredients in premixed mortars**

Ingredients	Mineral binders	Polymer binders	Aggregates	Additives
Effect	They cement the aggregates and other solids in the mortar mixture together and ensure good adhesion.	They improve flexibility, water repelling properties and adhesion to modern, often smooth building materials such as polystyrene or fibreboards.	Aggregates are especially sand. Sometimes coloured pigments are additionally used to make visible joints more attractive.	Additives improve the workability of the mortar such as water retention capacity. The mortar dries more slowly.

Special construction chemical admixtures and additives are what give modern mortars their amazing properties. Polymer components, which make mortar much easier to work and also bond better to different substrates, play a major role. Opposite liquid admixtures for concrete, these polymers are mixed with the mortar at the plant in powder form. This was made possible by a German invention during the 1950s known as spray drying. This allowed polymers (plastics), especially latex solutions, which are liquids, to be converted into a powder that can be easily mixed with the other mortar ingredients and packaged in sacks. While mixing the mortar with water, the powder is again distributed evenly in the original latex – it is redispersed. “To redisperse” means “to redistribute”. These powders are called dispersion powders.

In the following sections different types of mortar are presented in detail.

**4.2.1 Mortars for Joints and Laying Tiles:  
A Secure Hold on Any Wall**

Tiled walls and floors are omnipresent, practical and attractive. Tiles should have a long service life and not fall off the wall, even under the most difficult conditions. Thousands of feet trample on swimming pool tiles, they are washed daily with aggressive cleaners and are often permanently under water. In the case of terrace tiles, conditions are no better: in sunshine they can heat to more than 50 °C., in winter temperatures can drop to below -20 °C. In these conditions, tiles can change in length by several millimetres. Because of their brittle crystal structure, rigid tile cementing mortars on a pure

mineral cement base are not able to withstand such loads (expansion) and would detach after a short time. Even today, nearly 90 percent of all tile cements contain cement. The reason they do not detach is due to the construction chemical admixtures, dispersion powders and polymers or resins they contain. When the mortar hardens, the polymers form permanently elastic, plastic bridges between the brittle, mineral constituents of the mortar which decisively improve adhesion properties on different substrates. In the old days it was extremely difficult for tile layers to cement tiles to any substrates other than stone or concrete – for example tiles on tiles or tiles on wood, PVC or gypsum fibreboard. But with modern dispersion powders, this is no longer a problem. In addition, the plastic bridges increase the elasticity of the tile cementing mortar, making it insensitive to fluctuating temperatures and the changes in length associated with this referred to as expansion.

The water repelling properties of the mortar, called hydrophobicity, are also improved by polymers. Even in swimming pools, water does not penetrate into the tile cement which – at least on the outer area – could be damaged by frost over the course of time. Modern mortars also have another advantage: they can be applied quickly and easily which clearly reduces construction time and costs.

For a long time now, mortars have also been available that are tinted with various coloured pigments to match or enhance the colour of the tiles. The right joint mortar can be found for even for the most difficult cases: for pointing



Mural "Homet" by Sarah Morris

driveways paved with natural stone or parking areas that are driven over daily by hundreds of cars, delivery trucks and even 36-tonners.

But mortar must be more than just hard-wearing. In many cases, entirely other properties have priority. There are types of stone that deform when they absorb water – sandstone, for instance. To point or cement such stone, a special mortar is required that does not give off water and has high water retention capacity. For this purpose, cellulose ethers are added which are some of the most effective construction chemical admixtures – additives – used in dry mortars. A percentage of just 0.02 to 0.7 percent in the mortar suffices to considerably increase water retention capacity. Meanwhile there are even mortars with anti-bacterial additives that protect joints in baths and kitchens from infestation with bacteria or algae.

TABLE 4

Criteria that different modern joint mortars must meet

Traffic loads – fork lifts, pedestrians
Chemical loads – acids, lyes
Stress caused by thermal expansion
Cleaning – especially abrasive agents and high pressure cleaners
Wetting with water – especially for water reservoirs
Suitability for different building materials – for example different types of natural stone
Adhesion with different joint depths and widths
Colours according to wishes

TEACHER INFORMATION

- Worksheet 5: The Transport of the Emmaus Church
- Worksheet 6: Construction Chemical All-Purpose Cement: Mortar



Tiled swimming pools

#### 4.2.2 Waterproofing Grouts: To Keep Water Out

Waterproofing grouts form an effective barrier layer against water. They are typically used on basement walls, balconies and terraces and in damp rooms and swimming pools. Waterproofing grouts are used in these areas as a water blocking layer beneath tiles and sometimes they are even needed for enclosures in zoos.

Waterproofing grouts probably belong to the most unusual types of mortar. Thanks to their usually very high polymer content of up to 40 percent, they are more like a permanently elastic layer of rubber in the hardened state than a classic mortar. Experts speak of "flexible" or "highly flexible" waterproofing grouts. They are so elastic and, at the same time, durable that they can even bridge cracks several millimetres wide without tearing. Another variation of waterproofing grouts are the "rigid, mineral waterproofing grouts" which have a higher cement content and a much lower polymer content and are used for solid, hard substrates that do not have a tendency to crack (for example external basement walls).

#### NOTE

##### Why is waterproofing so important?

Regardless whether in the form of vapour, liquid or ice: Water is the most destructive element there is for building materials such as concrete, masonry work and natural stone. Experts distinguish between the different ways in which water can enter a building:

- Leaking baths, shower trays
- Condensation: breath moisture, water vapour
- Splash water from rain on the plinth of the building
- Ground damp in surrounding, loose soil
- Moisture, meaning water that has collected in deeper lying, denser soil. Moisture exerts only slight hydrostatic pressure on the building. Drops of water in baths or rain on a terrace is also referred to as moisture.

#### TEACHER INFORMATION

Experiment X: Waterproofing grouts

#### ILLUSTRATION 16

##### Flexible waterproofing grouts



Flexible waterproofing grouts essentially consist of cement, aggregates and a percentage of polymers.

#### ILLUSTRATION 17

##### Waterproofing grouts with and without the addition of polymers



The illustration shows two cardboard boxes. The box on the left was coated on the inside with a water repelling polymer waterproofing grout and holds the water. The box on the right was coated with a conventional waterproofing grout without polymers. It is not able to hold the water. After just a short time the water had softened the cardboard and the water leaked out.

### 4.2.3 Floor Levelling Compounds: Always Smooth

Self-flowing floor levelling compounds – what a monster expression! Practically everyone is familiar with the terms concrete, mortar or render but this special term is most likely unknown to most people. However: without self-flowing floor levelling compounds it would be practically impossible to produce a large-surface, smooth floor. They make school auditoriums so perfectly smooth that no chair wobbles and when a school disco is held there, no one stumbles. Floors in sport halls become an even playing field through floor levelling compounds and in large factory halls they ensure that speedy electric forklifts can glide gently without jolts. Once the carcass of a new building is completed, floor levelling compounds are used. These are also a special variation of dry mortar. They are applied in a relatively thin layer by pump and hose or simply poured out of a bucket on the coarse and usually rough concrete or screed floors. What is so fascinating: thanks to their special formulation, the compound distributes itself evenly over the floor like the flow of lava from a volcano over the countryside, filling unevenness in the floor as well as cracks and holes. If you have ever tried to pour mud out a bucket, you realise that this must be a special property. Usually, the heavy mud forms a mound while the water runs off. But that is not the case with floor levelling compounds: All the worker has to do is spread the honey-like, special mortar out a bit over the large surface with a kind of rubber wiper and the compound flows evenly, forming layers up to 35 millimetre thick, depending on the quantity applied and the application.



Consistence test

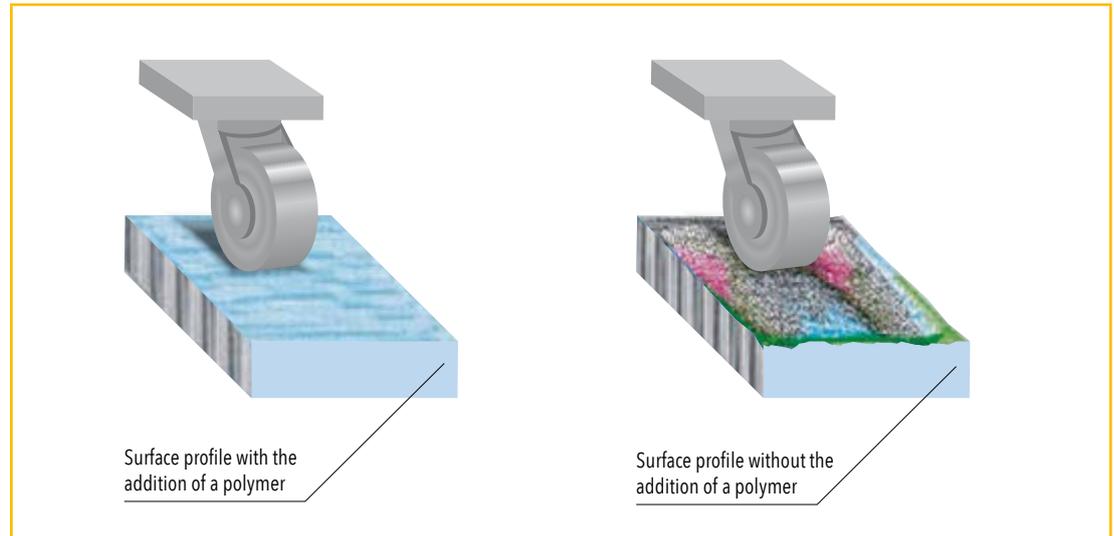
As with other types of mortars, it is dispersion powders in particular that make it possible to formulate the properties of floor levelling compounds for this specific application. These levelling compounds flow so well because the polymers arrange themselves into a molecular network and are evenly distributed. Polymers also contribute to strength. How durable and “abrasion resistant” floor levelling compounds that contain dispersion powders are is proved by the manufacturer with a so-called “wear test”: A small steel wheel is pressed on the hardened compound and rolled over the surface 10,000 times in different directions. Illustration 18 shows that a floor levelling compound that contains polymers clearly wears less.



Applying floor levelling compounds



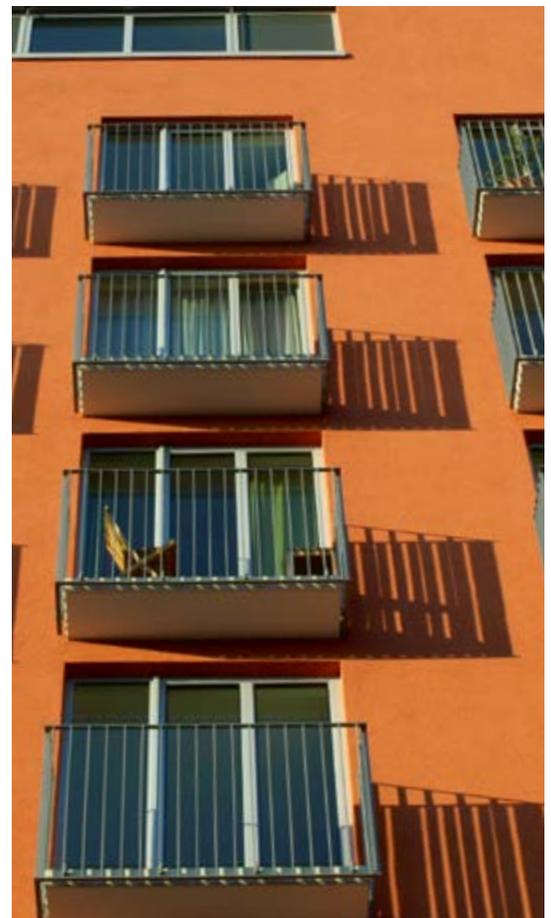
Wear test on different self-flowing filling compounds



4.2.4 Renders and Adhesive Mortars:  
Attractive Walls and More

“Rough fibre, white wallpaper” that was the wall decoration of choice just a few years ago in many flats and houses in Germany. In the meantime, many people no longer decorate the walls in their homes with classic wallpaper; they now use high quality renders – a further variation of premixed mortar. The range of renders available is enormous, also thanks to construction chemical admixtures. Those who like it simple and elegant select gypsum render. But if you prefer the rustic, comfortable charm of an Italian restaurant, you can decorate your walls with rough render. Experts divide renders according to their binders into the five following groups: lime mortar, lime cement mortar, cement mortar, gypsum mortar and anhydrite mortar. Depending on the binder, the renders are only suitable for use indoors or outdoors on external walls. The render has two tasks: it should permanently protect the building from the influence of water and it should be attractive. Today, all modern renders are produced centrally in plants and only need to be mixed with water at the building site.

Renders should be water vapour permeable – or diffusion-open. That especially applies to indoor rooms since the walls must be able to take up moisture in the room and vapours from the kitchen and bath to ensure a comfortable room climate. Otherwise, condensation quickly forms.



Rendered house facade with thermal insulation

#### 4.2.5 Building Insulation: Good for the Wallet and Good for the Climate

One of the most effective ways to reduce energy consumption in buildings is to thermally insulate the facade. Insulation prevents heat in interior rooms from being given off directly through the walls to the outside which reduces energy consumption noticeably. Considerably less oil or gas is required for heating. The possible savings are substantial – in Germany, for example, nearly a third of the primary energy\* used is needed just for heating private households. At the same time, more than 50 percent of all German housing units are not sufficiently insulated. If these flats were insulated with rigid foam panels made of polystyrene, for example, heating oil consumption per square metre could be reduced by up to two-thirds. The emission of carbon dioxide would be reduced by around 70 million tonnes annually – a clear contribution to climate protection! With a service life of 50 years, modern thermal insulation can save around 5,500 litres of heating oil per cubic metre insulation material or 19 tonnes of carbon dioxide.

##### ● Bonded Thermal Insulation Systems

Insulation for facades is installed as a so-called bonded thermal insulation system. The system is made of a multiple-layer sandwich construction consisting of thermally insulating materials such as Styrofoam, polyurethane foam, stone wool, light-weight wood-wool building boards or cork that are cemented to the external walls of the building. These insulation materials are attached with special adhesive mortars, dowels or mounting strips. The outside of the insulation is then coated with an undercoat render (reinforcement layer) and a finish (render, ceramic wall facing such as facing clinker or tiles) which should be water repelling yet water vapour permeable (diffusion-open).

##### 📌 TEACHER INFORMATION

Experiment XI: The insulating properties of polystyrene

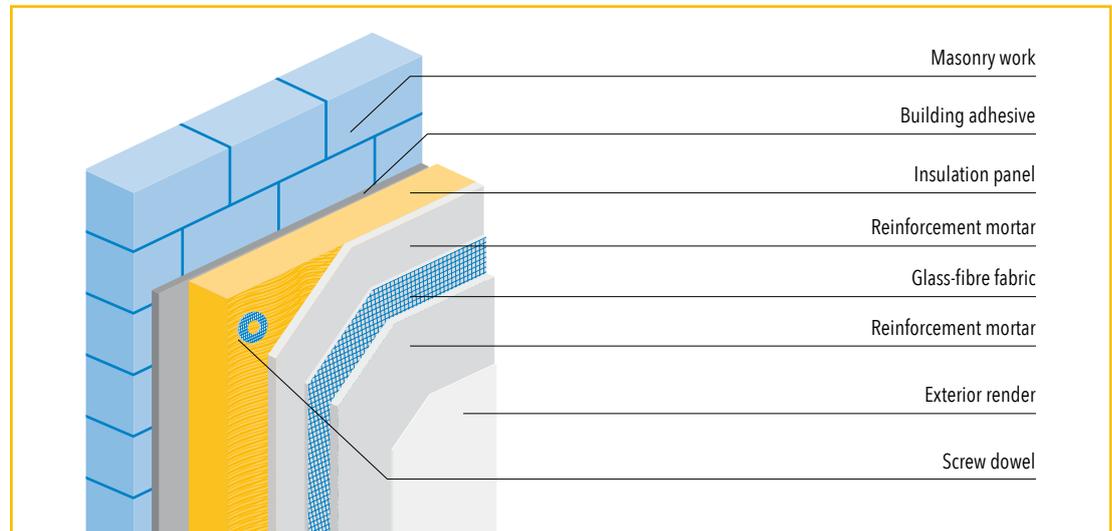
What sounds so simple is actually a real challenge because mortars do not really adhere well to smooth plastic surfaces. So how is it possible that render and the insulation panels adhere to each other so well that a bonded thermal insulation system can even survive the impact of a soccer ball at high velocity?

The reinforcement layer is especially important (the word “reinforce” originally meant to “equip with weapons”). In the case of reinforcement render, a thin and flexible glass-fibre fabric is laid in a cement based, premixed mortar. This layer of reinforcement makes a vital contribution to the stability of the entire construction. The reinforcement mortar must be especially elastic but also able to absorb impacts. To achieve this, the mortar is mixed with a polymer based dispersion powder. The challenge: the render should be elastic enough to be able to absorb impacts but strong enough to prevent the insulation panel below from being dented. After all, dents in the house wall caused by soccer balls or hail would not please the owner of the building. Once again, the right mixture of raw materials is important: cement increases the compressive strength, hardness and water resistance of the render. Too much cement makes the render brittle with a tendency to crack. The polymers are used to achieve the necessary flexibility and adhesion to plastic substrates.



Facade insulation

Schematic layer construction of a bonded thermal insulation system



Depending on wishes, the facade can be finished with render, wood, ceramic, clinker, tiles or metal cladding. If render is chosen, silicate renders on a cement or hydraulic lime base are often used. The render should absorb as little water as possible, be easy to apply, insensitive to cracks, durable and resistant to fungi, algae and pests and also have high water vapour diffusion capacity as well as a long service life. To meet these requirements, two layers of render are usually used in bonded thermal insulation systems – an undercoat render (reinforcement layer) and a finishing render (final coating). Coloured pigments can be added to brighten up facades.

#### 4.2.6 Repair Mortars

When it comes to repairing small, superficial damage, spalling on walls or filling holes in the building such as voids around heating pipes or utility lines, repair mortars are usually used. Repair mortars are mortars on a cement base with the addition of polymers. Thanks to polymers the mortar adheres better to the substrate than a pure cement mortar. Depending on the intended purpose, repair mortars with different polymers can be used that adhere well to different substrates. There are also repair mortars for horizontal and slightly sloped surfaces and even mortars for working over-head on ceilings.

So-called bonding layers are also mortars on a cement base to which polymers have been added. They improve the adhesion of the render to the substrate. When repairing concrete, bonding layers are used to provide a better

hold for the repair concrete used to repair the surface. Bonding layers can also serve as a moisture barrier between the substrate and outer skin. In some cases, they serve as corrosion protection at the same time and prevent moisture from the outside from reaching the reinforcement.



Application of repair mortar

## 4.3 Polymers in the Construction Chemical Industry: The Right Formulation for Every Application

Plastics, which are organic polymers, were extensively dealt with in the preceding pages – but mostly only as admixtures in concrete or mortar. In the construction chemical industry, polymers are more than just a means to improve the properties of other materials. They are essential working and construction materials by themselves. In the following pages, several important polymer groups will be presented in more detail. Most of the basic chemicals used in the construction chemical industry are produced in the plants of large chemical companies. The performance of the construction chemical industry is to optimally combine these basic substances with each other for the respective purpose and, by doing so, tailor-make new products with new properties that can be selectively formulated.

### 4.3.1 Reactive Resins

Reactive resins are liquid or liquefiable resins which react alone (single component systems) or together with reac-

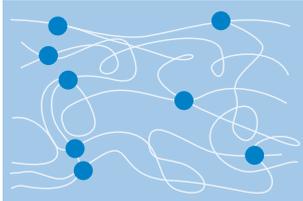
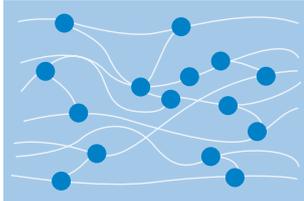
tive agents (multi-component systems) such as hardeners or accelerators. This reaction takes place by polymerisation or polyaddition reactions\* in which no volatile components are released.

#### • Epoxy Resins (EP)

An important class of polymers are epoxy resins. They belong to the group of polyethers which form through catalytic polymerisation of epoxies. Epoxies are reactive, cyclic, organic compounds. Epoxy resins form through the reaction of epoxies with a dialcohol, a so-called diol\* (polyaddition\*). This polymerisation reaction usually takes place so slowly that that epoxy resins, which are highly viscous liquids, can be very easily processed. The result is a stable and highly chemical resistant polymer that is especially used as a floor cover in the building trade. Epoxy resins and the polyurethanes dealt with further on are also abrasion resistant, making them suitable for industrial floors with heavy loads but also as sealing compounds for vats and tanks in which contaminated water is collected, for example at petrol stations or in chemical plants. Electrically conductive floors can also be produced with epoxy resins.

#### ILLUSTRATION 20

### Polymers

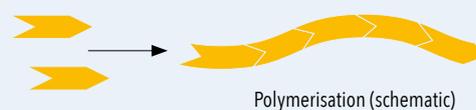
Thermoplastics	Elastomers	Thermosets
		
<b>Un-cross-linked</b>	<b>Loosely cross-linked</b>	<b>Densely cross-linked</b>
Polyethylene Polystyrene Polyamide (nylon) Polyester (Trevira)	Rubber Silicones Polyurethanes	Epoxy resins Polyester resins Phenolics Polyurethanes

Without epoxy resins, the robust CRPs (carbon fibre-reinforced polymer) used for the maintenance of bridges or towers would be unthinkable. CRPs have been used for a long time in different branches of industry such as the automobile and aircraft industries but also in the sport industry because they are not only light but can also be subjected to heavy loads. They can also be used for increasing or restoring the load-bearing capacity of buildings. CRPs consist of individual, practically infinitely long, very thin, high strength carbon fibres (filaments) that are combined into a bundle (roving) and then permanently bonded with liquid epoxy resin. When the epoxy resin cures, a high strength material results, for example a laminate for reinforcing a bridge.

#### NOTE

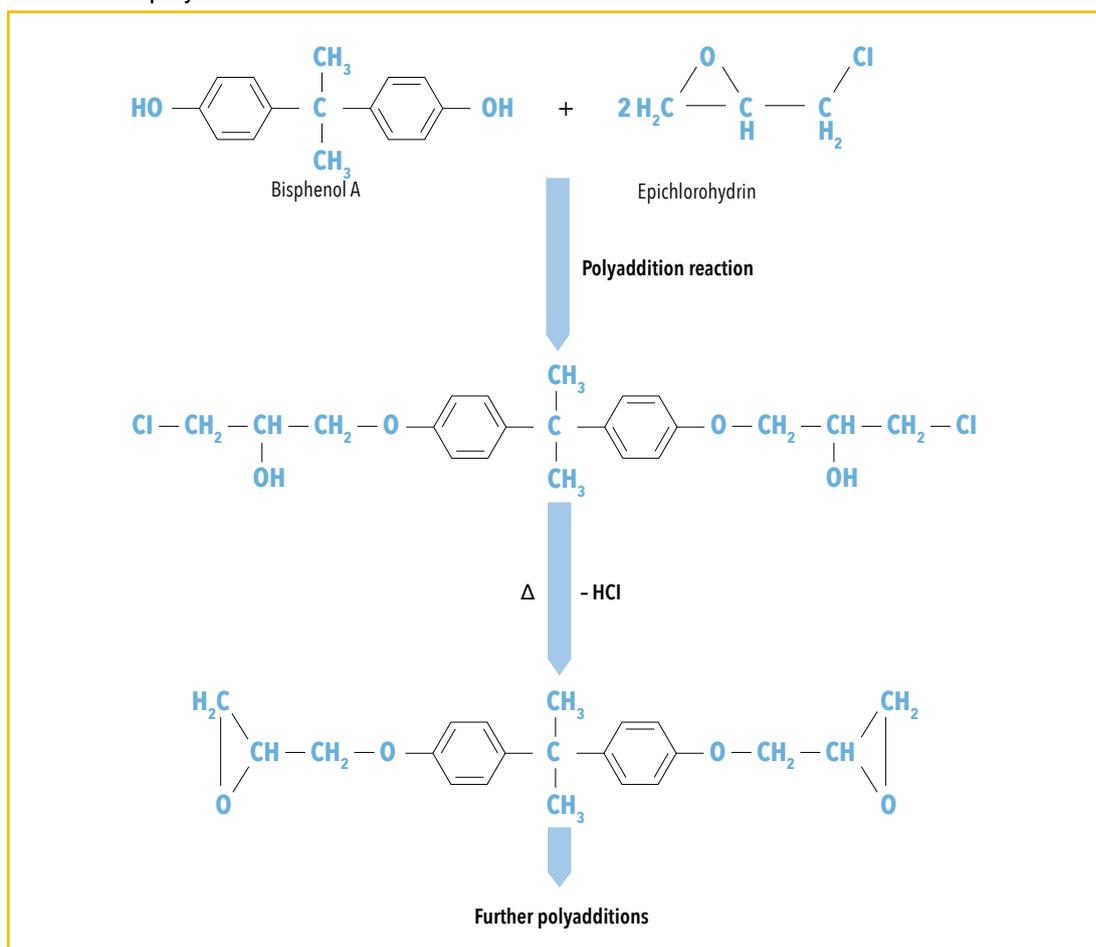
##### Polymers – a strong network

Polymers are simply what we call plastic, rubber or “plastics and elastics” colloquially. But behind these general terms there are thousands of products for thousands of applications that clearly differ from each other. Polymers can be translucent and as hard as a CD or soft and elastic like the foam inside an automobile seat. But all polymers have one thing in common: they are made from small single components called monomers that link to the large polymer network in a chemical reaction.

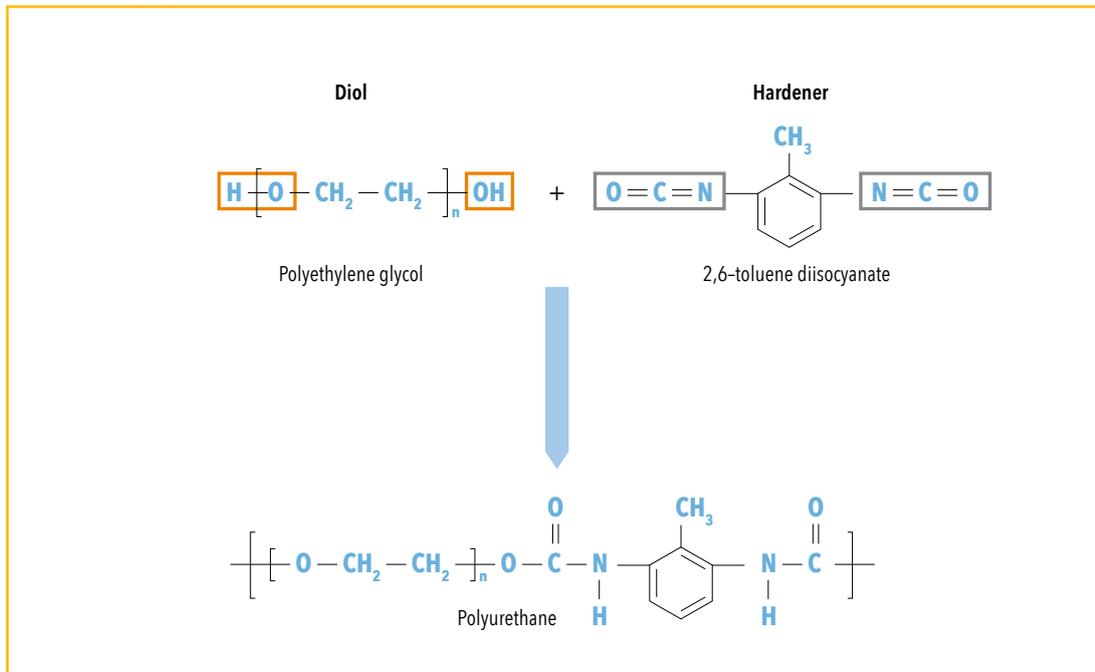


#### ILLUSTRATION 21

##### Formation of epoxy resins



Formation of polyurethane



● Polyurethane (PU)

Polyurethanes (PU) can be used to seal floors and waterproof bridges that are crossed by thousands of automobiles and lorries every day.

PU results when a diol (see Illustration 22) reacts with an isocyanate. Within just a few seconds, the monomers cross-link, becoming new macro-molecules, and the polyurethane cures. The name, by the way, is derived from the central "urethane group" (-NH-CO-O-) which is formed when the diols and isocyanates cross-link. Cross-linking takes place through a chemical reaction between the isocyanate group of the hardener (grey molecule fragment) and the hydroxyl function of the base component (orange molecule fragment) while forming a urethane function. Since the hardener as well as the base molecule each have two reactive molecule ends, long polyurethane molecules are formed step by step.

Basically, a distinction is made between single component polyurethanes which cross-link without the addition of a second (hardener) component and only need humidity while releasing carbon dioxide, and two component polyurethanes which consist of isocyanate, the so-called hardener component, and polyol, the base component.

The base and hardener are only mixed with each other at the building site, e.g. just before applying to a floor, and cure through an addition reaction (polyaddition\*).



A floor sealed with polyurethane resins

PU materials are used in many areas today: in the form of insulation for refrigerators and thermal insulation panels for roofs but also as packaging materials. In the building industry, PU is especially used as a joint sealant. When building houses, PU foams are used to seal joints between individual building elements or to fixate door and window frames. PU can also be used as a weather resistant floor cover for terraces or balconies that is both elastic and slip resistant.

PU foam is mixed directly in the spray can just before it is applied and can be metered exactly by pressing the actuator which opens the valve. It's amazing how much foam can swell out of a container the size of a beer can!

#### TEACHER-INFORMATION

Worksheet 7: Polyurethane  
Experiment III: Presentation of polyurethane



MMA floor coating in a supermarket

#### ● Methyl Methacrylate Resins (MMA)

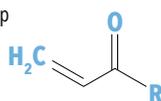
MMA, methyl ester of methacrylic acid, is especially known as acrylic glass or Plexiglas and has been used for a long time for shatterproof plastic windows or transparent roof covers. MMA is also a main component in modern dental prostheses made of plastic. But in the building industry MMA is mostly used as a resin for coating surfaces or floors since it is resistant to chemicals, robust and abrasion resistant.

MMA is especially suitable for quickly coating floors – for example in supermarkets. It can be applied evenings and has cured and can be subjected to loads by the next morning which means that sale can go on without interruption. MMA even cures quickly at extremely low temperatures such as those found in refrigerated warehouses. The use of MMA can therefore eliminate expensive interruption of production. MMA also forms by a polymerisation reaction.

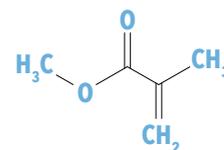
#### ILLUSTRATION 23

##### Formation of polymethyl methacrylate

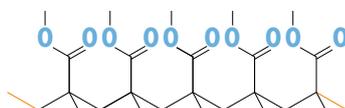
Acrylic group with an organic side group



Methyl methacrylate MMA



Polymethyl methacrylate PMMA (Plexiglas)



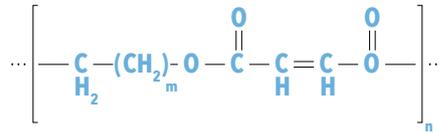
● **Unsaturated Polyester (UP)**

The unsaturated polyesters (UP) form through polycondensation\* from multivalent alcohols (glycols, glycerine) and dicarboxylic acids. As a rule, the still liquid polymers are combined with a load-bearing sheet of fabric called reinforcement. Together they produce a waterproofing material that covers the substrate. This allows flat roofs,

balconies as well as parking decks to be waterproofed. UPs are resistant to petrol and oil as well as weak bases and acids. That also makes them interesting as protection for reinforced concrete because they prevent solvents from penetrating which would cause corrosion of the concrete or the steel reinforcement.

📌 ILLUSTRATION 24

**Non-cross-linked polyester strand**



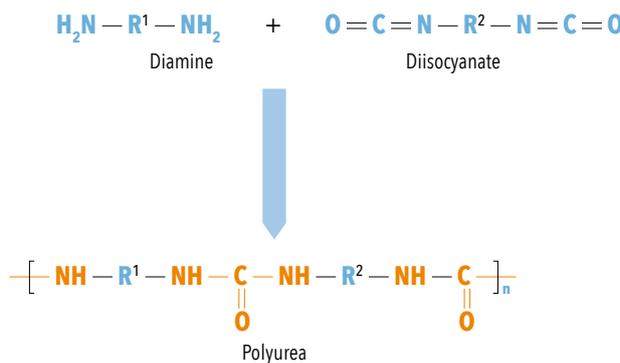
● **Polyurea (PUA)**

Polyurea is a comparatively young construction chemical product and has only been used on a large scale in construction for a relatively short time. Its properties, however, make it a very popular coating product. Polyurea forms through a polymerisation reaction of isocyanate with amines or mixtures of amines. A long chain and cross-linked polyurea molecule forms.

Since the chemicals react with each other and cure within a very short time, it can even be easily applied to steep walls in a spraying procedure. In 1990, just five tonnes of polyurea compounds were produced worldwide. By 2006, the quantity had increased to 35,000 tonnes. Polyurea coatings are resistant to mechanical and chemical loads, insensitive to water and form flexible, seamless and elastic films.

📌 ILLUSTRATION 25

**Formation of polyurea**



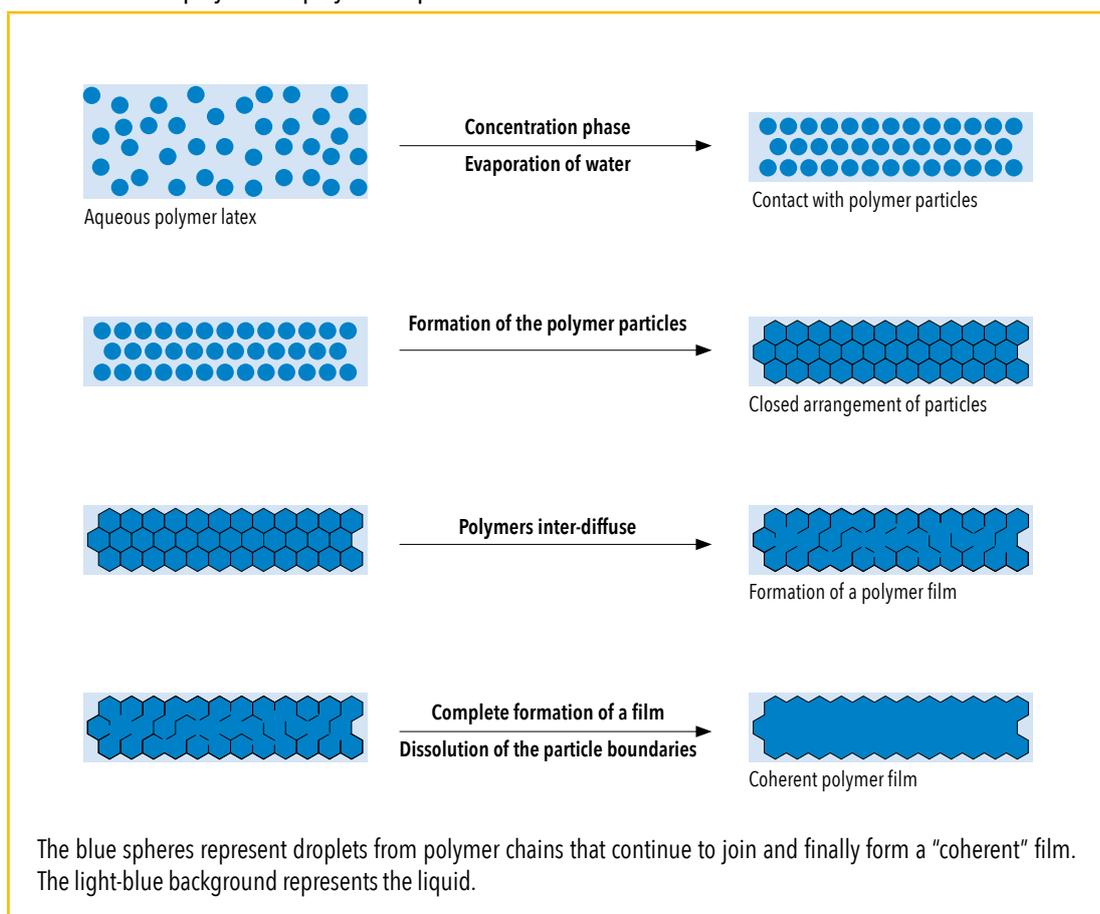
### 4.3.2 Polymer Dispersions and Redispersible Polymer Powders

In principle, polymer dispersions are nothing but finely distributed polymer particles in a liquid, the diameter of which can range between ten nanometres and several micrometres – dimensions that are not sufficient for a construction chemical product, of course. That is why polymers are further cross-linked by reactive additives. Polymer dispersions in paste form result that are excellently suited as a sealant or cement for bonded thermal insulation system panels or tiles. Sealants or cements on a polyacrylate base are often used – especially in interior finishing and particularly for dry lining. Their advantage: Acrylate sealants adhere to most substrates even if a

bonding layer is not applied to the wall first as a primer. They can be used for versatile applications, applied without any problems and remain permanently elastic when deformed. They can also be easily coated over. However, acrylate sealants are not suitable for floor joints and wet areas because they can still absorb water after they have cured. Polyacrylate sealants are polyacrylates that are dispersed in water or dissolved in solvents. They cure when the water or solvent evaporates. This means that there will be volume shrinkage in a filled joint of up to 25 percent, corresponding to the quantity of water/solvent that evaporates, a fact that the craftsman must take into account when injecting the joint with the sealant.

ILLUSTRATION 26

#### Mode of action of polymers in polymer dispersions



## 4.4 Silanes, Siloxanes und Silicone

To protect surfaces from water and soiling, they are treated with water repelling impregnation agents or hydrophobizing agents. Today, mainly silicones and silicone related products are used for this purpose.

### NOTE

#### An old hat - hydrophobization

Hydrophobization of building material by using oils was already known in ancient times.

Alexander the Great impregnated wooden bridge piers with olive oil to reduce the absorption of water.



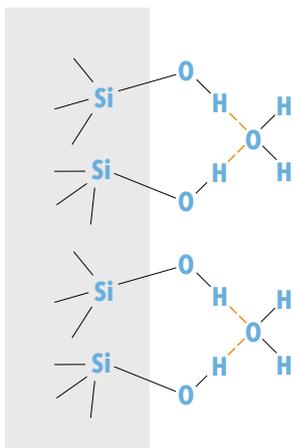
Cracks in sealants due to aging

There are four different, active hydrophobizing substances on a silicon base: silanes, siloxanes, silicone resin and alkali silicates, although the silanes and siloxanes are predominately used. A combination of these two active substances in particular allows the production of custom-made hydrophobizing agents.

All of these need moisture for the reaction to the final active substance, silicone resin, but moisture is found in sufficient quantities on every building material. The inorganic silicon oxide content (silicates) adheres to mineral substrates, the added organic structural elements, e.g. the methyl groups, cause the water repelling effect.

### ILLUSTRATION 27

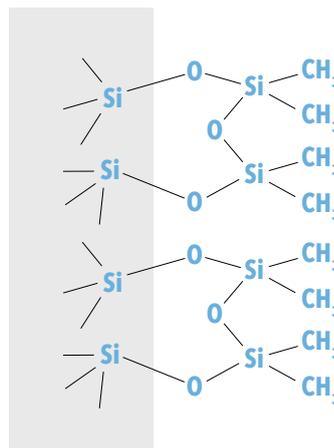
#### Hydrophobization



Water molecules are dipoles due to the different electronegativity of hydrogen and oxygen.

The polar siliceous OH groups of untreated mineral surfaces absorb polar water molecules.

**The surface is hydrophilic.**



Through the reaction of the polar siliceous OH groups with siloxanes, their polarity becomes masked.

The free, non-polar CH<sub>3</sub> groups of the siloxanes on the hydrophobized surface do not absorb polar water molecules.

**The surface is hydrophobic.**

Silanes and siloxanes are very soluble in organic solvents such as alcohol. It is logical that the penetration depth of the hydrophobizing agent directly depends on the concentration of the active substance: The lower the active substance concentration, the less it is able to completely coat the pores and capillaries. The consequence: A building material with little absorption capacity such as concrete will require a higher active substance concentration than a highly absorbent material such as brick. To adjust the different siloxane/silane systems for use on different substrates such as concrete or brick, these are mixed with water and emulsified. These emulsions, in which the silanes are finely distributed in the form of droplets in an aqueous solution or cream, are ready to use. The anti-graffiti coatings mentioned above, among others, are made of these.

Products on a silicone base are not only used for coating but also often as sealants. Silicone sealants cure by reacting with humidity.

Silicone sealants can be used practically everywhere. They are resistant to UV light, industrial gasses, mechanical abrasion and they are especially resistant to heat. That is why they are often used for cementing ceramic hobs. Since silicones are permanently elastic and allow deformation one-fourth the width of the joint, they are very capable of accommodating many of the movements of the material.



Silikondichtstoff

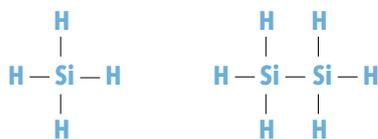
Among the sealants, they also come in the widest range of colours and are even available in a transparent version.

#### TEACHER INFORMATION

Worksheet 10: Synthesis of polysiloxanes

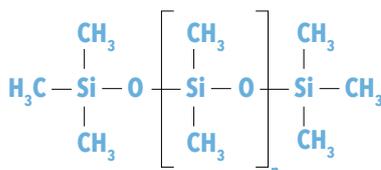
#### ILLUSTRATION 28

##### Silanes and siloxanes



Silanes have a covalent, single bond between the individual silicon atoms in the chain.

Designation is made analogous to the alkanes: monosilanes, disilanes, etc.



Polydimethyl siloxane

## 4.5 Polysulfides

Polysulfides are a further group of sealants. These are distinguished by high resistance to mechanical loads, resistance to weather and high resistance to fuels, sea water and oils. They are also highly resistant to temperature. Depending on formulation, polysulfides remain elastic like rubber in a temperature range between -50 and +90 °C, the reason why polysulfide sealants are used to seal insulated glass window panes. In winter, ice-cold wind blows on them and in summer they bake in the heat of the sun. They are also often used as a robust sealant in clarification plants, for drip pans in tank farms and in warehouses for chemicals. Just like silicones, polysulfides can deform one-fourth the width of the joint.



*Waterproofing a basement, bitumen primer*

## 4.6 Bitumen

If you have heard the word before, you probably think of a black, viscous mass that has a light tar odour – and that is not entirely wrong. Bitumen (from the Latin word Bitumen, “earth pitch”) is a naturally occurring mixture of different long-chain, aromatic hydrocarbons. Bitumen can also be produced by fractionated distillation\* from petroleum. And bitumen is one thing in particular: water repelling. No wonder that it plays a large role in waterproofing buildings – especially for external basement walls when constructing houses. But it is not used in its pure form for this purpose. So-called “polymer modified bitumen emulsions” (PMB) or bitumen thick coatings are used instead which are easy to apply as water based emulsions. They are applied to the external side of basement walls and other building elements that are continuously in contact with damp soil. As with mortar, the polymers added, such as polyethylene or polypropylene, increase the elasticity of the bitumen thick coating. They also increase resistance to aggressive substances in the ground such as acids found in humus. So-called bitumen sheets are offered for coating and waterproofing roofs that are rolled out on the roof like a thick film.



*Application of a bitumen thick coating*

In view of a change in the way energy is used and finite resources, requirements in regard to building and architecture are increasingly being reformulated.

Current research in the construction chemical industry focuses on sustainable construction. Scientists keep the entire life cycle of a building in mind, from the extraction of raw materials and planning to construction and utilisation all the way to renewal. The goal is to minimise the consumption of energy and resources as well as to protect our natural environment as far as possible.

Many products produced by the construction chemical industry are especially used where our environment is exposed to greater risks. For example with sewers, when building and protecting clarification plants, when waterproofing areas subjected to vehicle traffic at petrol stations, in and on noise abatement barriers or to prevent a loss of heat.

Therefore, the decisive contribution of a building material to environment protection lies in its potential to construct a need-based yet overall cost and environment saving building at the same time. The following examples are intended to illustrate this.

## ILLUSTRATION 29

### Influences buildings are subjected to

Mechanical	Physical	Chemical	Biological
Own weight Traffic loads Wind loads Earthquakes Wear	Frost Temperature Moisture	Salts Acids Bases Gasses Solvents Soft water	Bacteria Fungi/mould Algae Insects
<b>Examples</b> Homes, high rise buildings, industrial buildings, roads, bridges, airports, hydraulic structures, waterways ...	<b>Examples</b> Homes, high rise buildings, industrial buildings, roads, bridges, airports, hydraulic structures, waterways...	<b>Examples</b> Roads, bridges, industrial buildings, airports, petrol stations, sewage collectors, clarification plants, drinking water reservoirs ...	<b>Examples</b> Homes, high rise buildings, old buildings, heritage buildings, wood constructions, sewage collectors, clarification plants ...

#### ● Maintaining Buildings

As already stated, water is the greatest enemy of buildings. It usually penetrates unnoticed into the building until damage becomes visible. Expensive and time consuming repairs or new construction are the consequence – which actually means an unnecessary consumption of resources. So it is better to prevent water from entering in the first place. As described above, this is easily possible today with bitumen or waterproofing grouts and other materials. And even if water has already entered a building, the problem can often be remedied without great expense by using a salt storing render.

#### ● Saving Energy

The reduction of carbon dioxide emissions is one of the great challenges of our day. Insulating buildings with a bonded thermal insulation system can make a substantial contribution to this. As already mentioned, these systems would not be thinkable without special cements, reinforcement mortars and renders enhanced by construction chemical admixtures. But construction chemical products also contribute to saving energy indirectly. They make the construction of long bridges and tunnels possible. This considerably shortens traffic routes which in turn clearly contributes in saving fuel. In Switzerland, the world's longest tunnel is presently being constructed which will cross the Alps. In a few years, freight trains will speed through

the Gotthard Base Tunnel and make the many drives with lorries that still struggle over the winding passes today unnecessary. In road traffic areas, special materials ensure smoother roadways which reduce the rolling friction of tyres. That also saves petrol.

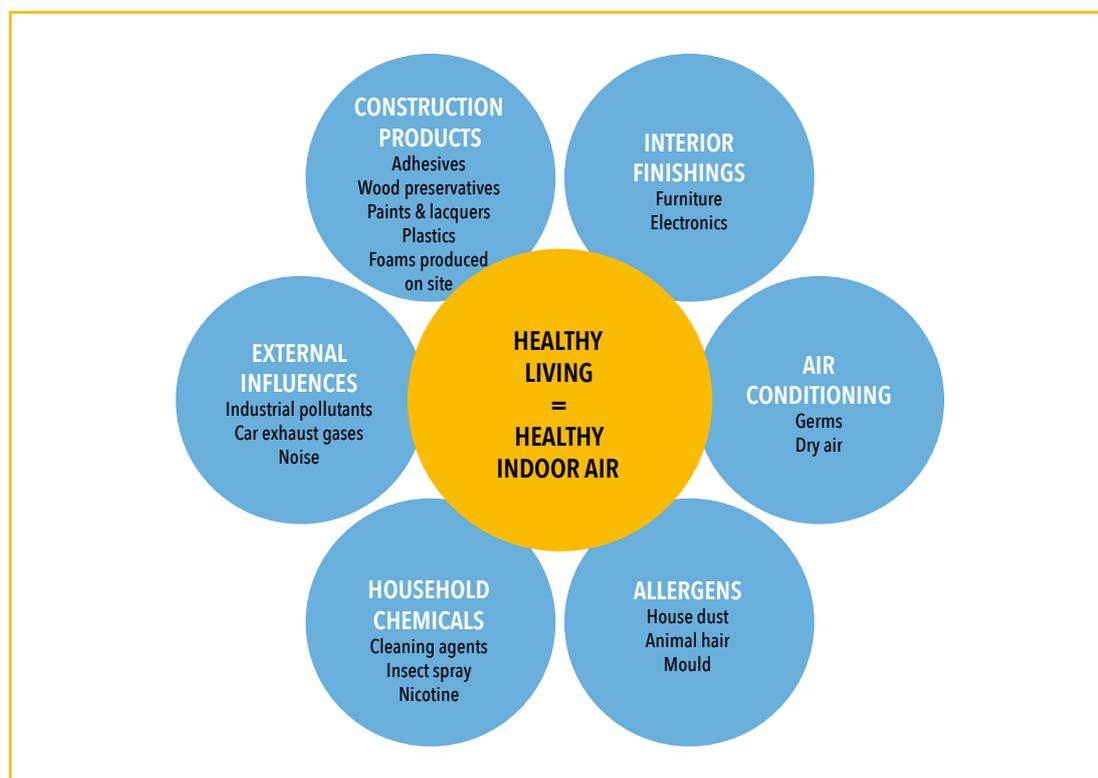
● **Healthy Living: No Thick Air Here!**

At our latitudes, people spend a good 20 hours each day in closed rooms. We breathe 10 to 20 cubic metres of air

each day, depending on age and how active the respective person is – the quantity of air in a small child’s room! That is why healthy indoor air is so important – it has an impact on our state of health. Materials that contain harmful substances can contaminate the air in homes, offices, kindergartens and hospitals and lead to health problems. Along with the effects of living habits such as airing, cooking or smoking, the emission behaviour of building materials also influences how healthy our indoor air is.

📍 ILLUSTRATION 30

Factors that influence indoor air



Up until the end of the 1970s, the subject of indoor air quality and possible emission of harmful substances from building products was not yet on the radar screen. It was only when a discussion began concerning chipboard that contained formaldehyde, substances that cause cancer such as asbestos or incorrectly used wood preservatives that the ball got rolling and public awareness changed. Health related aspects of building and living have continuously gained importance over the last years for manufacturers and users of building products. When it comes to emissions, the focus is especially on volatile organic

compounds (VOC): substances that are designated VOCs\* have a low boiling point and thus easily escape into the air from materials such as adhesives, paints as well as furniture and building materials but also from cleaning agents.

Manufacturers of construction chemical products have taken this change into account and have examined the ingredients as well as their release and effect. As a result, the products offered today are safe.



- **Protection of the Ground and Bodies of Water**

Regardless of whether you are dealing with a chemical tank, clarification plant or a petrol station: the operator must make sure that no liquids that are hazardous to the environment can leak into the ground, streams or rivers or reach ground water. To safeguard the environment, tanks/ reservoirs and surfaces are coated with hard wearing, chemical and oil resistant coatings. Epoxy resins, polyurethanes, polyurea and many other construction chemical products meet these requirements and remain impermeable for decades.

- **Conserving Resources**

Airy, filigree buildings can be constructed today with modern, high strength concretes that were usually only possible with steel before. This saves raw materials and energy and the lower mass and higher strength allow greater spans and ever higher structures. Extra floor space is gained by this. Since 1960, the maximum compressive strength of concretes has been increased fivefold! Current developments such as self-compacting concrete or acid resistant concrete improve the workability of concrete and the durability of buildings and are therefore more cost effective. Thanks to today's superplasticizers, the former practice of vibrating concrete so that it distributes uniformly in the formwork, which is time consuming and expensive, is no longer necessary.

NOTE

The subjects environment protection and construction chemical products are closely interrelated because they have several points in common. Construction chemical products can make a contribution in saving important raw materials and resources. Bonded thermal insulation systems for insulating houses would not be possible without special mortars. Waterproofing grouts and polymers make sure that sewage, heating oil and chemicals remain in their containers and cannot reach the environment. The protection of old buildings helps to save building materials. The active substances in construction chemical products must be environment-friendly, of course, and the materials should not release any problematical substances into the environment. Today, environment-friendliness and sustainability of a product is more important than ever if it is to be successfully introduced on the market. In a series of State-of-the-Art Reports published by Deutsche Bauchemie, construction chemical products are dealt with in regard to their relevance to the environment (go to [www.deutsche-bauchemie.com/publications/english/state-of-the-art-reports/](http://www.deutsche-bauchemie.com/publications/english/state-of-the-art-reports/)).



Clarification plant

- Safety for Humans and the Environment:

- Responsible Care

Since 1991, the chemical industry in Germany and many other nations has undertaken to independently continue to improve its safety, health and environment standards beyond legal requirements through the "Responsible Care" initiative. On the one hand, this commitment ensures that products in the construction chemical industry are as free as possible from harmful substances and that safety and environment protection in chemical plants continuously improves. But it goes beyond that: In view of the globalisation of world trade, many chemicals meanwhile come from different parts of the earth and from different production locations. "Responsible Care" aims to ensure that the same high safety standards apply for workers and production in all of these countries. On the other hand, finished products are exported to countries all over the world. In this case it must also be ensured that the chemical products are safe and will not harm the user – even if different regulations apply to construction sites in Africa or Asia than in Germany. This applies not only to the construction chemicals sector but the entire chemical industry.



*Responsible Care logo*



*Self-compacting concrete, Community Centre Mannheim*



*Metropol Parasol, Plaza de la Encarnación*

One rises forcefully and massively into the sky; others are impressive underground. All of them are wonders of technology: fascinating buildings such as skyscrapers, bridges, tunnels and dams. But these awesome structures are not the only examples for the high-tech products the construction chemical industry provides. Roof coatings that can withstand the blazing heat of the sun in the desert or protective coatings for enormous buildings are also among the most outstanding facets of construction chemical products. In the following chapter we will take a brief excursion into the world of architecture – and show construction chemical products in perfection.

- **Building to the Limit: A Wooden Giant**

In Spain, a new and airy space named “Plaza de la Encarnación” was created in the centre of the city of Sevilla where people can stroll, take a break and rest, and where cultural events are held. The architectural attraction there is the Metropol Parasol, an enormous, widely projecting roof structure that really looks like a gigantic parasol. This unique, airy and several storey high, new landmark provides welcome shade and is the ideal location for concerts or large theatre performances. Such a building must be effectively protected from weather, of course. A protective skin was created by applying a polyurea mixture in a spraying procedure. Polyurea is elastic and flexible enough to adapt to the natural movements of the wood and is also water vapour permeable. There is no doubt about it: architects seek to create increasingly unusual structures with free shapes. Sprayable and flexible polyurea will be the coating of choice in many cases.

- **Building to the Limit: High Performance Concrete Right up to the Sky**

Not only in Sevilla but also in other cities in the world, the trend to build extraordinary buildings that rise high into the sky is unbroken: In 2004 the “Taipei Financial Center” (also called “Taipei 101”) opened in Taiwan. With a height of 508 metres, the office tower looms over Taiwan’s capital Taipei like a gigantic bamboo pole – in an area that is constantly at risk of earthquakes and cyclones. To make

sure that the tower does not buckle like young bamboo in a typhoon, an enormous, gold-plated steel pendulum that weighs 730 tonnes hangs in the 92<sup>nd</sup> storey, the world’s largest tuned mass damper. When a typhoon causes the tower to sway, the ball-shaped damper moves in the opposite direction, helping the building to remain upright.

To construct the foundation, 557 concrete pillars, each one and a half metres thick and up to 80 metres long were rammed into the ground. The builders then placed a slab on the pillars made of 9,000 tonnes of steel and 26,000 cubic metres of concrete. The main load of the tower is supported by eight enormous columns. Each “mega column”, as structural engineers call them, consists of 80 millimetre thick steel walls which were pumped full of high performance concrete all the way up to the 62<sup>nd</sup> storey to reinforce the building. Just for comparison: At 508 metres, the “Taipei 101” is taller than the Commerzbank in Frankfurt, the highest building in Europe, by more than 200 metres. But in the meantime, even this building has slipped to second place in the ranking of the world’s tallest buildings. It has been surpassed by the 830 metre high Burj Khalifa that opened in Dubai in 2010.

*Taipei Financial Center*



### ● Building to the Limit: The Longest Concrete Slab in the World

The slab is 280 metres long, 24 metres wide and one metre thick: the longest concrete slab in the world according to the builder, was poured in one piece at the site of Deutsches Elektronen-Synchrotron (DESY) in Hamburg. For two and a half days, concrete transport vehicles continuously delivered more than 6,600 cubic metres of concrete from a total of four concrete mixing plants. The concrete slab is the structural core of a vibration-free experimental hall in a particle accelerator.

In a concrete laboratory set up just for this purpose, specialists tested the properties of the concrete first before it was released for the construction site. To be able to produce this concrete monster in one piece, values such as the water/cement ratio, temperature and consistence had to meet exact specifications. The one meter thick hall floor made of high performance concrete which contained high performance plasticizers on a polycarboxylate ether base was placed in two layers: The bottom layer was placed in the classic manner and reinforced with conventional steel mats and bars. Above this is a 50 centimetre thick layer that was additionally reinforced with two different kinds of steel fibres to guarantee great toughness and high tensile strength. Five concrete pumps simultaneously conveyed concrete into the hall, working slowly from the centre of the almost 300 metre long concrete slab towards both ends. Extremely interested, concrete construction experts



Deutsches Elektronen-Synchrotron (Desy), Hamburg

from all over Germany came to watch the construction of this unique project in December 2007. One of the tricks used to produce the slab in one piece was to produce it on a thin layer of bitumen so that the concrete could glide stress-free. When the concrete shrinks during hydration,

the slab should be able to deform free of stress to prevent cracking. Since the temperature rises when the slab sets – up to about 40 °C – the viscosity of the bitumen is reduced and it acts like a parting plane. After the concrete has cooled, the layer of bitumen becomes solid again and the slab lies quietly like a monolithic block. Afterwards, the surface was sealed with a layer of epoxy resin.

#### NOTE

The construction chemical industry is not only involved in extracting and processing raw materials to produce construction chemical products and building materials but also in the construction of buildings and their protection, restoration, maintenance and repair. How many construction chemical products are used in a building is seldom obvious because the layman only sees outwardly visible evidence, for example facade coatings. Construction chemical products are hidden from sight for the most part.

### ● Building to the Limit: Development of New Building Materials

Light transmitting concrete is one of the most amazing materials developed in recent times: With the aid of optical fibres, concrete mutates from a heavy to a feather-light material – at least to the eye of the beholder. Production has been very time-consuming and costly so far but a new production process introduced in September 2006 takes a step in the direction of series production. A specially developed fabric made of optical fibres is used for production. A high degree of light transmission is achieved by a uniform arrangement of the fibres. Layers of this fabric are alternated with layers of especially fine concrete – layer for layer – 2 to 5 millimetres thick. The thinner the layers, the more light that passes through the concrete. The percentage of fabric needed to achieve this amazing effect is very low. The transmission of light through the optical fibres is so effective that you can see not only light but also shadows and even colours through the concrete – even when the walls are very thick. The goal now is to be able to produce larger formats in the future. Even metre-thick concrete constructions almost seem to have the lightness of Japanese rice paper walls. The strength of light transmitting concrete is in the range of high strength concrete since the percentage of light transmitting fibres is relatively low. There are numerous ideas for using light transmitting concrete: as room dividers, stair steps, interior furnishings and for exclusive installations in wellness areas.

- **Mass with Class**

The overwhelming majority of construction chemical products are used for the production and application of other building materials. That makes it difficult to quantify their economic significance in figures. These substances are often hidden in the products of other industries (for example ready-mixed concrete or premixed mortars). In the year 2013, the German construction chemical industry produced raw materials and products worth nearly ten billion Euro for the German market alone and the same amount again for the European construction industry. That makes the construction chemical industry a branch of industry in Germany that should not be underestimated; not least because they supply important export goods. In light of the fact that construction chemical products are mainly used and processed in other industries, it becomes clear how significant the construction chemical industry actually is. Today, practically every cement contains a construction chemical admixture and additives.

The German ready-mixed concrete industry produces 40 million tonnes of concrete each year with the aid of cement that is delivered to construction sites by approximately 10,000 truck mixers from 2,000 concrete plants. That means 200,000 cubic metres every day – enough to fill 150 large swimming pools! No other building material is produced in Germany in such large quantities and around 90 percent of the ready-mixed concrete produced contains special construction chemical concrete admixtures.

The premixed mortar industry is also a large customer of the construction chemical industry and this includes plants of the construction chemical companies themselves. In Germany, 300 companies produce approximately 15 million tonnes in which even more construction chemical admixtures are used per tonne than in ready-mixed concrete.

- **Preserving Buildings: From Corrosion Protection to Cultural Heritage**

Iron rusts, acids destroy concrete: corrosion, the undesirable decomposition of materials through substances from the surroundings has economic consequences of enormous proportions. Investigations have shown that the costs that result to preserve a steel construction are often much higher than the original construction costs.

#### NOTE

Experts estimate that in the leading industrial countries, approximately four percent of the gross national product is lost by corrosion: Tendency rising.

Today, the road leads straight to the construction chemical industry when dealing with the preservation of buildings or monuments because fewer and fewer new buildings have been constructed in Germany for many years now. The consequence: More and more old buildings need to be refurbished. The construction chemical industry supplies suitable materials for this and plays a leading role in preserving our cultural heritage. In many cases, substances are even tailor-made for certain applications. In 2006, when the Holstentor in Lübeck was restored, the restoration mortar had to be perfectly matched to the remaining historical mortar. The same applied for the reconstruction of the Dresden Frauenkirche [Church of Our Lady].



Holstentor, Lübeck



Frauenkirche, Dresden

#### • Creative and Progressive

According to an assessment made by the Centre for European Economic Research (ZEW) in Mannheim, the construction chemical industry plays an outstanding role in promoting innovations in Germany. In the German construction chemical industry, for example, every tenth employee is active in research. The results are clear because important developments came and still come from Germany: superplasticizers for light-weight and self-compacting flow concretes and screeds, long-term retarders for premixed concrete and mortar, coatings for permanent protection as well as concrete curing agents or waterproofing agents for concrete road construction are only a few examples. One aspect in current research is the use of renewable raw materials. Among these are, for example, plant oils and fats for concrete release agents. Thanks to various admixtures and additives, the appearance of high quality concrete is so appealing today that fair-faced concrete can be used to fulfil architects' most demanding requirements. By using special techniques, even photographs can be transferred to concrete in a large format. Protective coatings with nano particles protect such concretes from soiling and prevent the ingress

of liquids and spotting. Another new product with great potential for the future is ultra-high performance concrete which is especially dense and forms practically no pores or micro-cracks, thanks to construction chemical admixtures and very fine aggregates. It is almost as strong as steel and especially filigree, allowing economical buildings to be realised. Its high strength makes it an ideal building material for bridges with wide spans, halls and especially for columns that must support especially heavy loads.

#### 📌 TEACHER INFORMATION

Experiment VII: Lotus effect in a model experiment

Nature itself has also supplied many ideas for new developments. Recognising and systematic realisation of natural phenomena is the task of bionics, an interdisciplinary science in which scientists, engineers, architects and designers work hand-in-hand. A current example in the construction chemistry area is the lotus effect to produce self-cleaning surfaces.

The future will show what is possible.

**A**

**Acetone cyanohydrin** – forms through the addition of hydrogen cyanide and acetone.

**Anhydrite** – ( $\text{CaSO}_4$ ) is an often found, naturally occurring mineral that belongs to the group of sulphates. It converts to gypsum  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  through retention of water.

**Autoclaved aerated concrete** – Concrete that contains air pores in its structure in the hardened state.

**C**

**Calcium hydroxide** – ( $\text{Ca(OH)}_2$ ). Slaked lime forms under strong heat development from burnt (unslaked) lime ( $\text{CaO}$ ) and water.

**Carbonation** – Formation of calcium carbonate  $\text{CaCO}_3$  (limestone) from the calcium hydroxide ( $\text{Ca(OH)}_2$ ) of the hydrated cement due to the effect of carbon dioxide. The carbon dioxide can come from the surrounding air or through the addition of carbonated water.

**Cement paste and cement suspension** – relatively flowing capable mixtures of cement and water that are suitable as a repair system and also good for filling cracks or repairing other damage on concrete. The quality of the concrete or mortar depend on the weight ratio of water and cement, the water/cement ratio.

**D**

**Diols** – are organic compounds that contain two hydroxyl groups ( $-\text{OH}$ ). Diols are thus divalent alcohols. A simple example is ethane-1,2-diol (ethylene glycol).

**F**

**Fractionated distillation** – Method of separating liquid mixtures

**H**

**Hydraulic** – Hydraulic binders require water for their strength forming chemical reaction. They harden with water and remain solid in air as well as under water. Cement in concrete and mortar sets through a reaction with water. This chemical insertion of water molecules in (cement) crystals is called hydration by mineralogists. Cements are thus hydraulic binders.

**Hydration** – Chemical reaction of a substance with water. In the case of cement: When cement bonds with water while setting and hardening, hydrated cement forms from the cement paste.

**P**

**Polyaddition** – a chemical reaction in which simple molecules, called monomers, are added to one another to form long-chain molecules, called polymers without by-products. The molecules of the monomers join together, and the polymeric product is formed of repeating units, and is identical with that of the monomer. The molecular weight of the polymer is the total of the molecular weights of the monomers

**Polycarboxylate ether** – (PCE) are anionic polymers. They consist of a main chain and many side chains. Their structure has the appearance of a comb, the reason why polymers of this type are also called comb-shaped polymers.

**Polycondensation** – is a stepwise condensation reaction that takes place through stable but still reaction capable intermediate products in which macro-molecules (polymers/copolymers) are formed from the many low molecular substances (monomers) while releasing molecules with a simple structure (usually water).

**Polymerisation** – Chemical combination of simpler molecules with the same or different simple compounds (monomers) to larger molecules while giving off heat but without releasing (condensation) small reaction by-products.

**Primary energy** – is the energy found in natural gas, petroleum or coal which cannot be directly utilised and must be changed first into a usable form of energy such as electricity or heat (final energy).

## R

**Reinforced concrete** – sind flüssige oder verflüssigbare Harze, die für sich allein (Einkomponentensysteme) oder zusammen mit Reaktionsmitteln (Mehrkomponentensysteme) wie Härtern oder Beschleunigern durch Polymerisation oder Polyaddition reagieren.

**Reactive resins** – are liquid or liquefiable resins used alone (single component systems) or together with reactive agents (multiple component systems) such as hardeners or accelerators that react through polymerisation or polyaddition.

## S

**Silanes** – are a substance group of chemical compounds that consist of a basic silicon framework and hydrogen.

**Siloxanes** – are chemical compounds with the general formula  $R_3Si-[O-SiR_2]_n-O-SiR_3$ , while R can be hydrogen atoms or alkyl groups.

## V

**VOC** – abbreviation for volatile organic compounds. VOC is the term used for substances in gas and vapour form of organic origin in air. These include hydrocarbons, alcohols, aldehydes and organic acids. Experts distinguish VOC from very volatile organic compounds (VVOC) and the semi-volatile organic compounds (SVOC). The sum of the concentrations of all VOC is the total volatile organic compound (TVOC) value.

- Deutsche Bauchemie e. V., Frankfurt  
Concrete Admixtures and the Environment  
State-of-the-Art Report, 5<sup>th</sup> edition, 2011
- Deutsche Bauchemie e. V., Frankfurt  
Epoxy Resins in the Building Industry and  
the Environment  
State-of-the-Art Report, 2<sup>nd</sup> edition, 2009
- Deutsche Bauchemie e. V., Frankfurt  
Jahresbericht 2012/2013
- Deutsche Bauchemie e.V., Frankfurt  
Methacrylate Resins in the Building Industry and  
the Environment  
State-of-the-Art Report, 2<sup>nd</sup> edition, 2012
- Deutsche Bauchemie e. V., Frankfurt  
Polyurea in the Building Industry and the Environment  
State-of-the-Art Report, 1<sup>st</sup> edition, 2009
- Deutsche Bauchemie e. V., Frankfurt  
Polyurethane in the Construction Industry and  
the Environment  
State-of-the-Art Report, 2<sup>nd</sup> edition, 2012
- Ettel Wolf-Peter, Kunstharze und Kunststoffdispersionen  
für Mörtel und Betone  
Beton-Verlag, Düsseldorf, 1998
- Grübl Peter, Weigler Helmut, Karl Sieghart und Kupfer  
Herbert, Beton: Arten, Herstellung und Eigenschaften  
Ernst & Sohn, 2001
- Henning Otto und Knöfel Dietbert, Baustoffchemie:  
Eine Einführung für Bauingenieure und Architekten  
Verlag Bauwesen, 2002
- Hillemeier Bernd, Skriptum zur Vorlesung Baustoffe  
und Baustoffprüfung I und II  
Technische Universität Berlin, 2010
- Hillemeier Bernd et al.  
Spezialbetone, Betonkalender 2006  
Ernst & Sohn, 2006
- IBK Darmstadt  
Bauen mit Kunststoffen,  
Ernst & Sohn, 2001
- Karsten Rudolf, Bauchemie – Ursachen,  
Verhütung und Sanierung von Bauschäden  
C.F. Müller Verlag, Heidelberg, 2003
- Dietmar Klausen, Rudolf Hoscheid, Peter Lieblang,  
Technologie der Baustoffe  
15. Auflage, VDE Verlag, Berlin, 2013
- Kusterle W., Hillemeier B., Feix J., Verstärken und  
Instandsetzen von Betonkonstruktionen 2007  
Berichtsband der 7. Internationalen Fachtagung, Berlin,  
13./14.9.2007
- Lamprecht Heinz-Otto,  
Opus Caementitium – Bautechnik der Römer  
Vbt Verlag Bau u. Technik, 2001
- Mallon Thomas, Bauchemie  
Vogel Buchverlag, 2005
- Palmengarten der Stadt Frankfurt, Xylem und Phloem –  
Natur- und Kulturgeschichte des Holzes  
Sonderheft 33, 2000
- Plank Johann, Skriptum zur Vorlesung Bauchemie und  
Bauchemische Materialien  
Technische Universität München, 2012
- Scholz Wilhelm et al., Baustoffkenntnis  
Werner Verlag, 2011
- SIVV-Handbuch – Schützen, Instandsetzen, Verbinden  
und Verstärken von Betonbauteilen, Ausbildungsbeirat  
Verarbeiten von Kunststoffen im Betonbau  
Berlin, Deutscher Beton- und Bautechnik-Verein e. V. –  
DBV, Fraunhofer IRB Verlag, 2009
- Vitruv, De Architectura Libri Decem, Baukunst,  
2 Bde., Bücher I–X  
Birkhäuser Verlag, 1987
- Vollhardt, C.: Organische Chemie.  
WILEY-VCH, Weinheim 2003
- Wacker-Chemie, Wacker Silicones. Begreifen und Ver-  
stehen. Schulversuche mit Wacker-Siliconen, Chemie  
zum Anfassen und Begreifen – Learning by Doing.  
Wacker-Schulversuchskoffer für den naturwissenschaft-  
lichen Unterricht, 2004

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