NM EPOXY HANDBOOK

Third edition 2004
Presented by
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NILS MALMGREN AB

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Contents

Introduction

Knowledge of materials has always been necessary for those who design. With to-day's stringent demands on quality regarding manufacture, materials and execution, it is often assumed that purchasers, architects and contractors possess the necessary knowledge of that with which they work.

The *NM Epoxy Handbook* has been written to provide knowledge of the properties of epoxy plastic in a large number of different applications.

We have collected our knowledge primarily on low molecular epoxy and its use. It is our hope that the book will contribute to making product selections easier as well as finding the best solutions for each project.

History

Epoxy plastic has its roots far back in history, to be specific, in 1936, when Dr Pierre Castan in Switzerland succeeded in synthesising an epoxy resin that he hardened with phthalic acid anhydride.

In 1939. Dr S.O. Greenlee in the USA developed epoxy resins of epichlorohydrin and bisphenol A, i.e. the type of epoxy resins we use today. The purpose of the development of epoxy resins was to find a binding agent for coatings that were resistant to alkali, but it was soon shown that the epoxy had significantly more good properties than this. Today epoxy has its given place in aerospace, electronics and the automotive industry, as well as in foodstuffs, pharmaceuticals, manufacturing, offshore and the marine industry. Most people are familiar with the word epoxy and associate it with something that is strong.

Back in 1960, Nils Malmgren and Curt Augustsson began to formulate and produce products based on epoxy with hardener. In 1967, the scope had become so wide that Nils Malmgren AB was founded, specializing in epoxy-based products.

The company was quality certified in 1990 and could thus strengthen its purposeful quality approach.

Epoxy plastics' general chemical and physical properties

An epoxy resin is defined as a molecule with more than one epoxy group, which can be hardened into a usable plastic. The epoxy group, which is also called the glycidyl group, has through its characteristic appearance given the name to epoxy.

Epoxy group
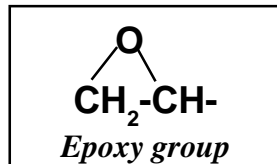
What one sees is an oxygen atom on the outside of the carbon chain. Epi means "on the outside of" and the second part of the word comes from oxygen.

There are two spellings, namely epoxi and epoxy. The first comes from the oxygen's bond with the carbon chain being called an oxide. Epoxy resin is manufactured from simple basic chemicals that are readily available.
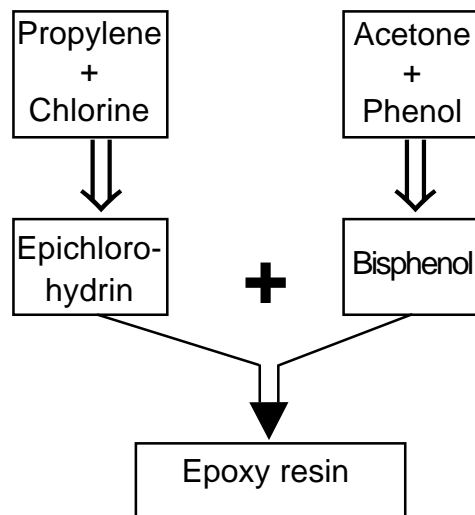
With the help of chemical formulas, the last stage out is as follows:

Bisphenol A   Epichlorohydrin

Diglycidylether Bisphenol A (DGEBA) epoxi resin
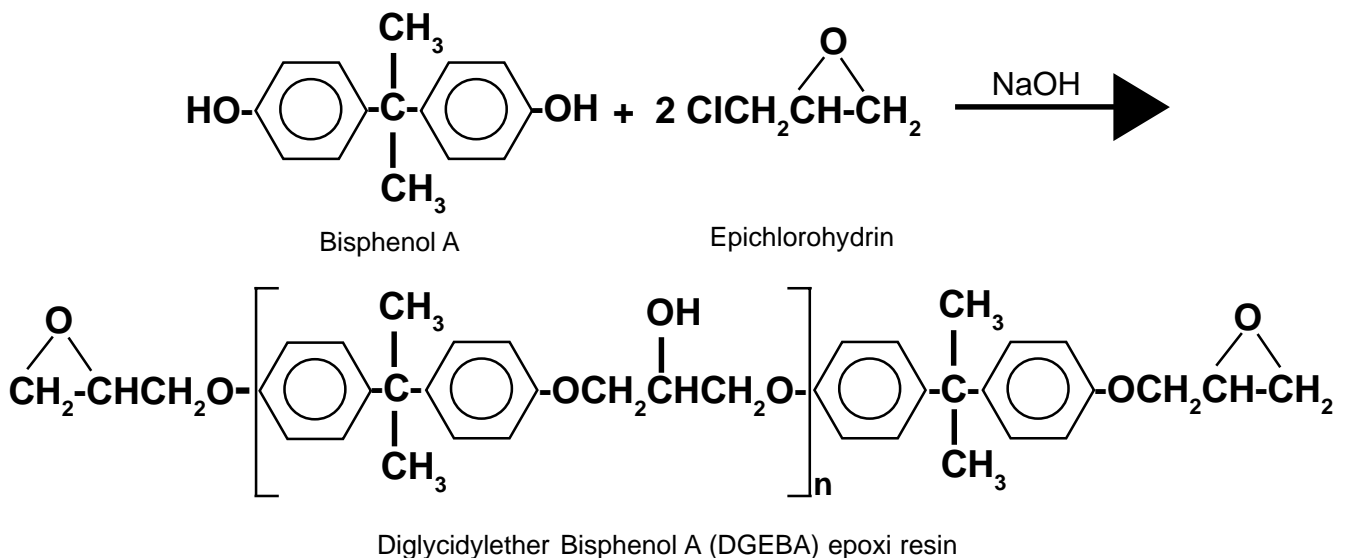
By varying the relationship between bisphenol A and epichlorohydrin, various molecular weights are obtained for the completed epoxy resin. The lowest molecular weight an epoxy resin of the DGEBA type can have is 340, but if two elements together can form different molecular weights when they react, the epoxy resin will contain a mixture of epoxy molecules of varying lengths. One therefore does not refer to the epoxy resins' molecular weight, but rather to their mean molecular weight. Epoxy resin with a mean molecular weight of over 700 is called high molecular, and epoxy resin with a mean molecular weight of under 700 low molecular. Epoxy resins can be allergens, and it is the molecular weight that determines how great the risk. The higher molecular weight, the lower the probability for allergies.

In the formula for epoxy resin, the letter "n" is seen after the brace. If n=0, i.e. that which is inside the brace does not exist, we then have the shortest epoxy molecule with a molecular weight of 340. It has the highest reactivity and thus also constitutes the greatest allergy risk. If n=1, the molecular weight is 624, for n=2 it is 908, etc. For each time n increases by 1, the molecular weight increases by 284. In a low molecular epoxy resin with the mean molecular weight of 380, the distribution is approximately 88% n=0, 10% n=1 and 2% n=2. A pure epoxy resin with n=2 is not an allergen, but if we look at a commercial epoxy resin with the molecular weight of 1080, the distribution is approximately 20% n=0, 15% n=1, 15% n=2 and 50% n=3, 4 and 5. This means the even a high molecular epoxy resin can be an allergen.

A low molecular epoxy resin with a mean molecular weight of 380 is fluid at room temperature, while an epoxy resin with a mean molecular weight of 1000 is solid at room temperature. The molecular weight determines what the epoxy resin can be used for.
The low molecular can be handled without solvent additives, which evaporate and are therefore used for casting, thick coatings, gap-filling glues, etc.
The high molecular epoxy resins must as a rule be dissolved in organic solvents to be manageable, which limits usage to paints and lacquers.

To convert epoxy resin to epoxy plastic, a reaction with a suitable substance is required. Such a substance in this context is called a hardener.
Examples of substance groups that function as epoxy hardeners are: amines, amides, acid anhydrides, imidazoles, boron trifluoride complexes, phenols, mercaptans and metal oxides.
For hardening at room temperature, amines and amides are primarily used, and to a certain extent mercaptans. The other hardener types generally require temperatures above +150°C to react with the epoxy. From this point forward, only amines and amide hardeners will be further described.

Amines are substances that are closely related to ammonia (NH_3). Depending on how many hydrogen atoms that are replaced by alkyl groups, primary amines NH_2-**R**, secondary amines **NH-R$_1$** or tertiary amines **N-R$_2$** arise. The total number of amino groups determines if the amine is a monoamine (**NH_2-R**), a diamine (**NH_2-R-NH_2**) or a polyamine (**NH_2-R-NH-R-NH-R-NH_2**).

Furthermore, the amines are divided into aliphatic, i.e. a straight carbon chain, cycloaliphatic with a ring-shaped carbon chain and finally aromatic where the amino group is bonded to a benzene ring.

As hardener for the epoxy resin, primarily diamines and polyamines are used.

The primary amino group **NH_2** contains as seen, two hydrogen atoms and one nitrogen atom. It is the hydrogen that constitutes the reactive part, and the reaction occurs with the oxygen in the epoxy group.

With somewhat simplified chemical formulas, it looks like this:
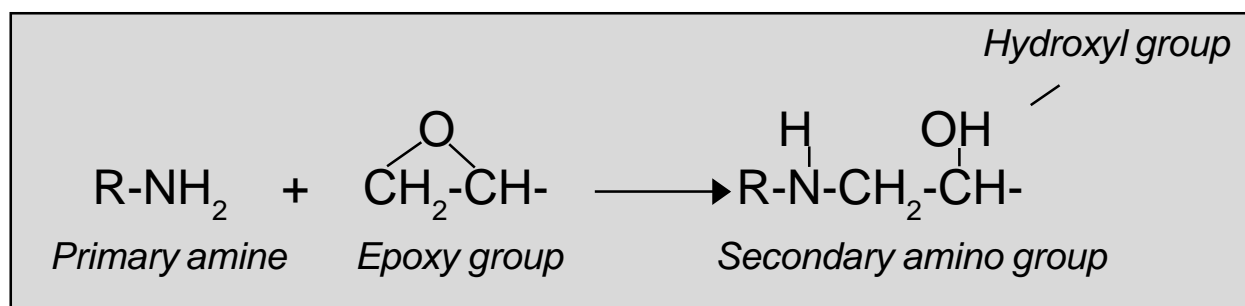
In the first reaction phase, one of the amine's hydrogen atoms reacts with the epoxy group's oxygen, causing the formation of a hydroxyl group (**OH-**) at the same time as the primary amine is reduced to a secondary amine. The reaction continues:
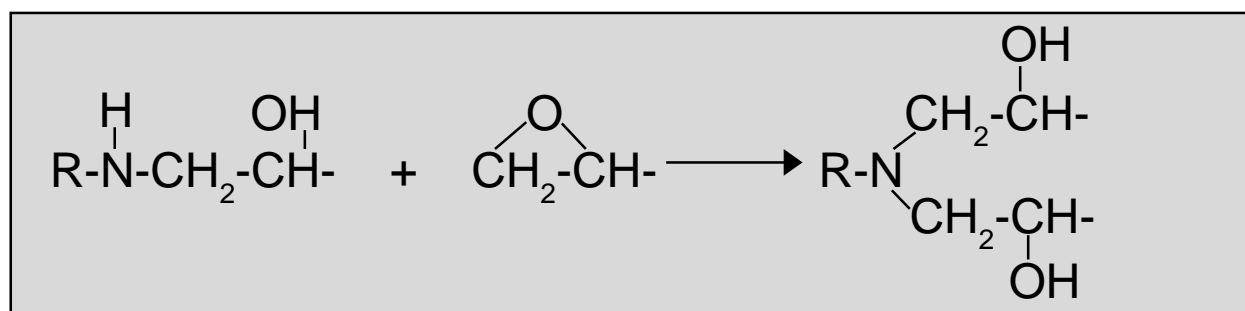
The secondary amine reacts with yet another epoxy group and the reaction is complete.

An epoxy molecule normally contains two epoxy groups, and one primary diamine has four reactive hydrogen atoms. A schematic of the epoxy plastic then looks like this:
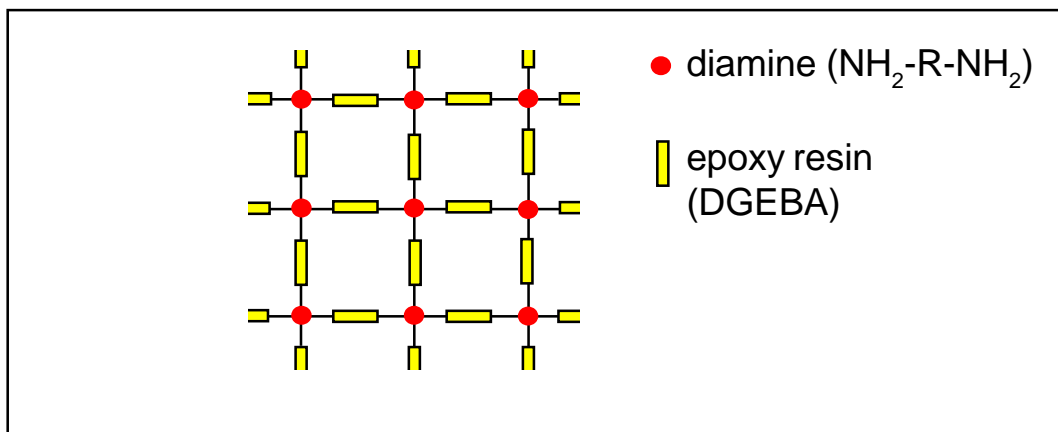
The epoxy plastic molecule is of course three-dimensional in reality.

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Examples of amines that are used as hardeners for epoxy resins:

Aliphatic amines
  • Diethylenetriamine
  • Triethylenetetramine
  • Aminoethyl piperazine
  • Trimethyl hexamethylenediamine

Cycloaliphatic amines
  • Isophorondiamine
  • Diamino-dicyclohexylmethane

Aromatic amines
  • Diaminodiphenylmethane
  • m-Phenylendiamine

It is very common to pre-react the amines with a certain portion of epoxy resin. The purpose of this is to attain a hardener that is less fluid than the pure amine and that has a somewhat higher reactivity.
This type of hardener is called amine adducts, and reacts largely in the same way as previously shown.

The next large group of hardeners is the amides, or more correctly expressed, the polyaminoamides. An amide is formed when a polyamine reacts with a fatty acid.

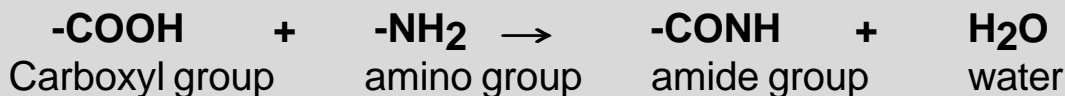$$-COOH \quad + \quad -NH_2 \quad \rightarrow \quad -CONH \quad + \quad H_2O$$
Carboxyl group   amino group   amide group   water

This generally applies to all polyamides, even nylon. By varying the relationship between fatty acid and amine, one can decide if the polyamide will be acid-terminated (of the type nylon) or amine-terminated, i.e. which end groups the polyamide will have. Only amine-terminated polyamides can be used as hardeners for epoxy resin. As fatty acid, most often used is tall fatty acid, linolic acid or olein. The fatty acids use either monomer (one carboxylic group) or dimer (two carboxylic groups). As polyamines, diethylenetriamine, triethylenetetramine and tetraethylenepentamine are used. The hydrogen in the amide group (**CONH**) is not reactive, but it is rather the hydrogen in the primary amino groups at the polyamide's ends and the secondary amino groups that are derived from the polyamine, which are reactive with the epoxy resin in the same way as previously described.

Both amine adducts and polyamides can be made water soluble. Such solutions have the capacity to emulsify low molecular epoxy resin, which in turn provides the possibility to manufacture water soluble epoxy paints.

The reaction between an epoxy resin and a hardener is an irreversible poly-addition, i.e. no by-products are formed, and the epoxy plastic cannot be decomposed into epoxy resin and hardener. The reaction is exothermic, which means that heat is released. Depending on the type of hardener one uses, one can achieve very large differences in reaction speeds. This has significant practical importance when working with epoxy. The time it takes to consume a mixture of epoxy resin and hardener is called **potlife**. Depending on the mixture's reactivity, potlife can vary from a few seconds to several years.

Potlife can be determined in several ways.
One method is to temper the epoxy resin and hardener to +20°C. Thereafter an amount of 100 grams is mixed in a plastic cup. The time for the mixture's temperature to reach +50°C is set as the mixture's potlife. For systems with low reactivity (long potlife), one most often chooses to measure the viscosity or consistency, and measure the time until the initial viscosity is doubled.

Both of these methods are unusable for aqueous emulsified or aqueous dispersed systems. In this case, one instead performs a lay-up test and measures the time to gloss reduction.

Most chemical reactions follow Arrhenius' law, which states that the reaction speed doubles for each tenth of a degree the temperature is increased. This means that a reaction is twice as fast at +30°C as at +20°C.

The larger the amount that is mixed together, the greater the amount of exothermic heat that is created. There is not enough time for this heat to be dissipated through the mixture vessel's surface, so instead it heats the mixture. As the temperature increases, the reaction speed also increases, which entails that the potlife is shorter, the larger the amount that is mixed.
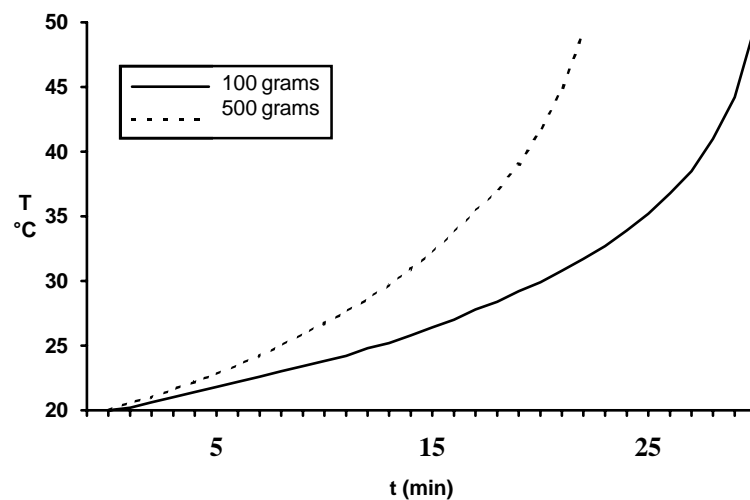
*Example of potlife for 100 and 500 grams of
the same epoxy resin/hardener mixture*

Potlife for an epoxy system consequently provides certain information to the user on working time after mixture, but one must consider the amount of material mixed, and the material's initial temperature. The epoxy's **hardening time** is defined as the time from the epoxy being applied until the formed epoxy plastic has achieved its final properties pertaining to strength and chemical resistance.

For epoxy that is applied in thin layers, the exothermic heat will not increase the temperature in the layer to any significant degree, but instead, the epoxy quickly assumes the temperature of the substrate. The reaction between the epoxy resin and hardener then goes relatively quick at the beginning because of the large availability of reactive molecules, and because the mobility of the molecules is high as long as the viscosity is low.

As complete epoxy molecules are formed, the number of reactive molecules is reduced at the same time as the viscosity increases. The reaction speed gradually slows.

As a rule of thumb, room temperature hardened epoxy needs about 7 days at +20°C to attain maximum properties, but already after 24 hours, one can have attained about 70–80% of the final properties.

Arrhenius' law naturally applies even if the reaction occurs at a constant temperature. This means that if the substrate is at +10°C, it takes about 14 days to attain final properties.
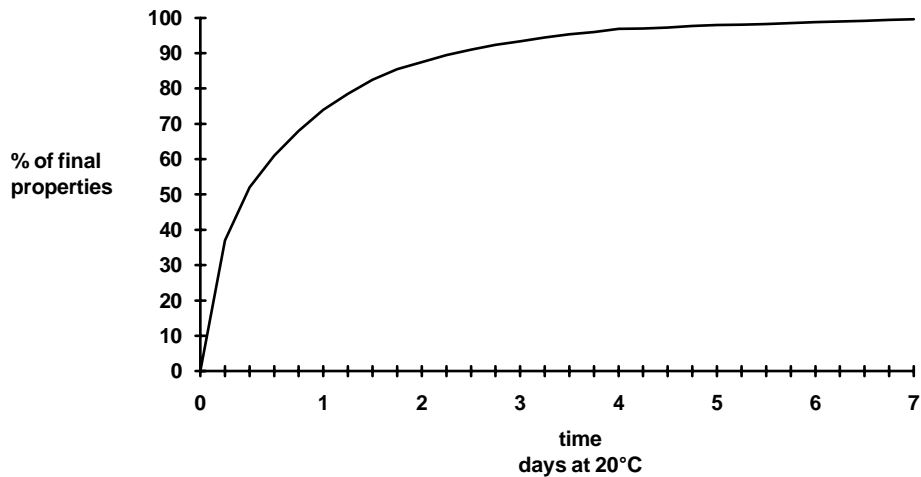
Example of epoxy's hardening process at constant temperature.

Epoxy plastic's characteristic basic properties

Currently more than 50 different substances fulfil the definition for an epoxy resin. If one also adds that there are several hundred different hardeners, it is easy to understand that epoxy plastic's properties can be modified to satisfy the most varied requirements. Nevertheless, certain basic properties are always present.

Adhesion

One of epoxy plastic's most characteristic properties is the capacity to adhere to most substrates. The reason for this is the presence of polar hydroxyl groups, and the ether bonds. The negligible shrinkage also entails that contact between the epoxy plastic and the substrate is not disturbed by tensions. The epoxy plastic's surface tension is most often under the critical surface energy for most materials. This is one of the requirements for adhesion to be achieved.

Mechanical strength

No other hard plastic can display as high mechanical strength as correctly formulated epoxy plastic. Again, it is largely because of the minimal shrinkage that built-in tensions are avoided. The tensile strength can exceed 80 MPa.

Chemical resistance

Thanks to the possibility of varying the epoxy plastics' properties, one can make epoxy plastic resistant to most chemicals. In general, epoxy plastic is very resistant to alkali, which is of importance in surface-treating concrete.

Diffusion density

Epoxy generally has relatively high vapour transmission resistance, but with a special technique, epoxy plastic can be made open to diffusion. Epoxy that is open to diffusion can be applied on, for example, wet concrete and provide adhesion higher than the concrete's tensile strength.

Water tightness

The epoxy plastics are to be considered as watertight and they are often used to protect against water.

Electrical insulation capacity

Epoxy plastics are excellent electrical insulators. Volume resistivity is normally $10^{15}\,\Omega\cdot\text{cm}$. This in combination with high moisture resistance and chemical resistance makes the epoxy suitable for both the manufacture of electronics components and the embedment of transformers.

Shrinkage

The epoxy plastics have very slight shrinkage during hardening. This is because the epoxy molecule has a rather small reorientation during the hardening process compared with, for example, polyester and methylmetacrylate.

Heat resistance

When it comes to heat resistance, room temperature hardened epoxy plastic differs very little from heat hardened. One often specifies heat resistance with **HDT** (Heat Deflection Temperature) or **Tg** (Glass transition temperature).
At HDT, the mechanical strength declines quickly. Room temperature hardened epoxy seldom attains HDT above 70°C, while heat hardened can reach 250°C.

Modifiable

Perhaps the chief property of epoxy is the nearly unlimited capability to modify the final properties of the epoxy plastic to meet special requirements. It is primarily the hardener that influences the plastic's properties, but as presented in the next chapter, there are many other substances that influence epoxy products.

Stability in light

Epoxy plastics based on aromatic epoxy resins are sensitive to light in the UV range. Direct radiation with ultraviolet light quickly causes yellowing. Even normal sunlight contains enough ultraviolet radiation for yellowing to occur. Most resistant are aliphatic epoxy resins with anhydride or amine hardener.

Modification of epoxy resins

Viscosity at 25°C of an unmodified low molecular epoxy resin of the DGEBA type, is about 10 Pa·s, at 20°C about 24 Pa·s and at 15°C about 68 Pa·s.
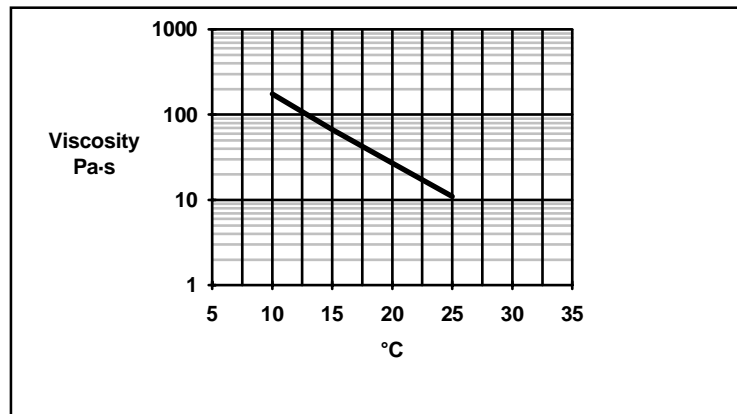
It is easy to understand that an unmodified epoxy resin cannot always be used out-doors or where the temperature is low. The first reason for modification is thus viscosity reduction to a suitable working consistency. Several options are available here.

First, we have **non-reactive** diluents, which refers to such substances that can be mixed with the epoxy resin but that do not participate in the reaction between the epoxy and hardener. Included here are the ordinary solvents such as xylene, toluole, glycol ethers, ketones, lower alcohols, etc.
Other non-reactive diluents include a large number of substances with sufficiently low vapour pressure that they do not evaporate from the hardened plastic under normal conditions. Examples of these are benzyl alcohol and coumarone resins. The substances that are not chemically bonded in the epoxy plastic molecule are to be imagined as deposited between the plastic molecular chains.
In this group are the "ordinary" solvents that have the strongest influence on viscosity, but which often entail a dangerous path.
Epoxy resin has very high solvent retention, i.e. the capacity to retain solvents. This means that it will take a long time before the solvent has evaporated. In a 1 mm thick layer, solvent residue can be detected after several months at room temperature.
Damage that can arise from solvents is usually blistering, either through high heating or because of osmosis when moisture occurs in concrete. Another reason to avoid solvents is the shrinkage effect that can result in layers detaching from weak substrates.

The diluents that under normal conditions do not evaporate affect the epoxy plastic's properties in other ways than viscosity reduction. Positive changes can be flexibility, improved resistance to water and salt solutions because of hydrophobing, improved reactivity, in part because the mobility of the epoxy and the hardener molecule is better at lower viscosity, and in part because of the catalytic effect from hydroxyl groups in, for example, benzyl alcohol.

Negative changes are degraded heat resistance and larger thermal expansion. At higher temperatures, volatility can be substantial with several of these substances. This can result in shrinkage with cracking and subsequent reduced adhesion. Another aspect that sometimes must be considered is the compatibility with bitumen. A minority of the non-reactive diluents do not bleed in bitumen. Furthermore, many diluents in this group are esters that can saponify upon contact with concrete under the influence of water.

Reactive diluents (thinners)

These substances have, as the name implies, the capacity to react with the epoxy resin or hardener, so that in this way, bond in the plastic molecule.

The most used types are those that contain one or more epoxy groups. There is a very large group of such substances that all can give the final plastic different properties.

What characterizes these substances is that they cannot migrate, evaporate or be extracted from the epoxy plastic. Heat resistance declines somewhat in comparison to unmodified epoxy, but not at all as much as in the case of the non-reactive diluents. A valuable property of the reactive diluents is that they reduce the surface tension of the epoxy resin, which in turn can improve wetting capabilities and thus adhesion. Depending on the reactive diluent's composition, both flexibility and chemical resistance can be affected.

Other substances used to modify the epoxy plastic's properties are, for example, high molecular isocyanates, which via the hardener, can react with the epoxy resin. The result is a plastic with rubber-elastic properties, which are retained down to about -40°C.

Such modification changes the epoxy plastic's fundamental properties. Heat resistance and chemical resistance decline with increased elasticity. At the same time, the viscosity increases because the isocyanates in themselves are very highly viscous. This means that further modification is necessary to reduce viscosity.

The next group of modification substances is pigments and fillers. Pigment is used to colour the epoxy material, and the filler to increase the mechanical strength and to reduce costs.

The pigments used are most often metal oxides such as titanium dioxide, iron oxide and chromium oxide.

As a rule, fillers are finely ground minerals and quartz sand. It is important that both pigments and fillers are properly dispersed in the epoxy binding agent.

In addition to the listed modification substances, there are a number of aids to affect such things as rheology, i.e. consistency, flow, air bubbles and adhesion.

It is easy to understand that an epoxy product has a relatively complex composition, where the included components shall interact for the results to be as intended.

Epoxy plastic application areas

Marine constructions
8,4%

Packaging and strapping
10,5%

Miscellaneous
3,8%

Automotive
7,9%

Aircraft
10,5%

Powder
16,3%

Electrical and
electronics
24,2%

Construction and civil
engineering works
18,4%
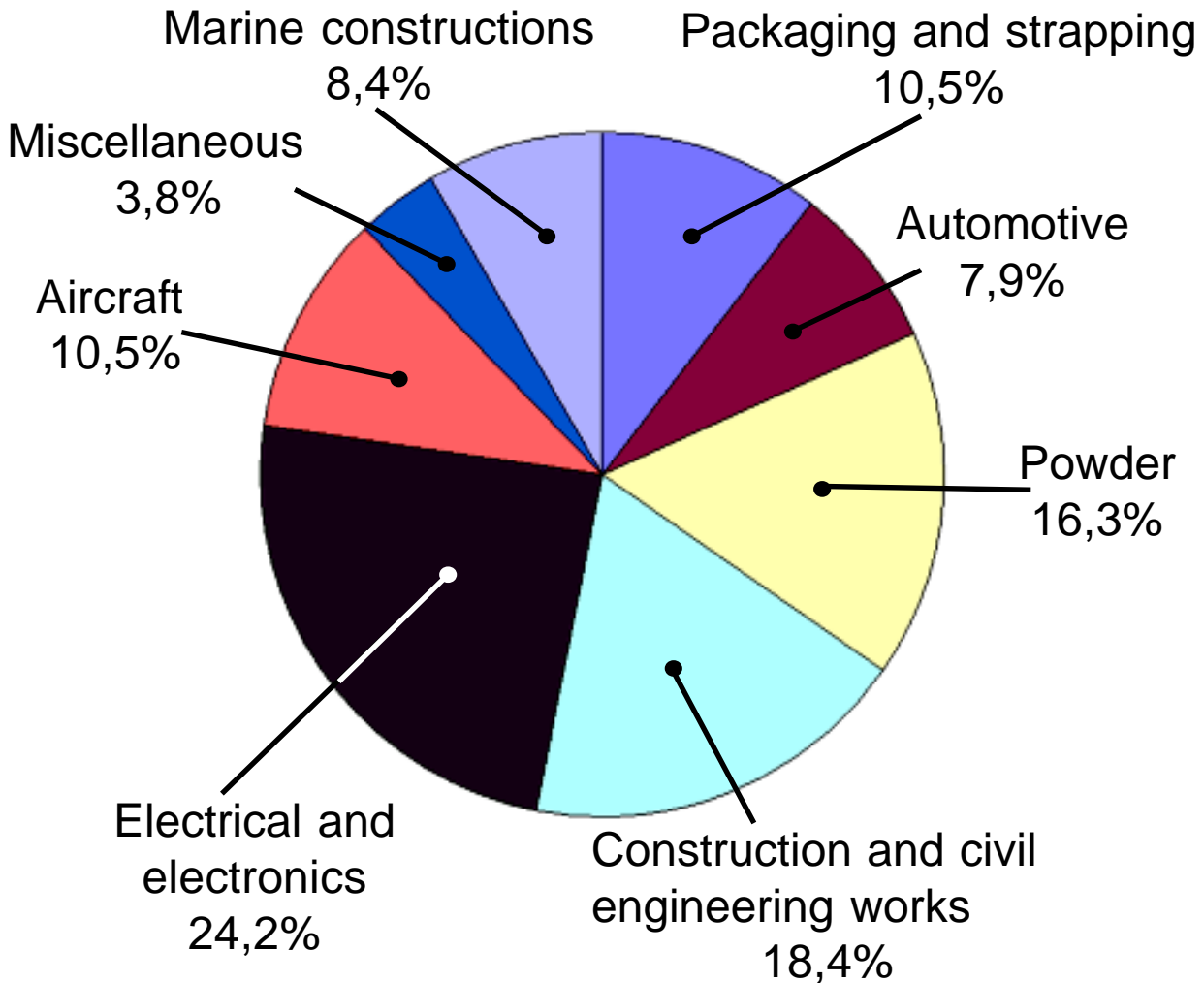
Construction and civil engineering works

The largest amounts of epoxy plastic in the construction industry are used for coating of concrete floors. Untreated concrete floors are impractical for many reasons. They are difficult to clean and therefore unsanitary. Spill of, for example, oils are drawn into the concrete and cannot be removed. The chemical resistance of concrete is not especially high. From a purely wear perspective, it is often important to have a surface coating of some kind. An epoxy product intended for floor coating normally has a compression strength that is three to four times that of concrete.

The epoxy resins that are normally used for floor coating are the liquid low molecular resins. These resins normally contain no solvents, which entails that thick coatings can be applied on a single occasion. Furthermore, floor coating work presents no risk for fire.

Most epoxy coatings are applied to protect something. A special variant are the coatings in the pharmaceutical and foodstuffs industry, where the epoxy plastic's freedom from pores make walls and floors easier to clean and thus protects operations from bacteria and contamination. Another variant is epoxy plastic as a moisture barrier to protect plastic mats and parquet from rising moisture and alkali.

• Impregnation and sealing

The simplest coatings for concrete floors are for impregnation and sealing. These are achieved with low viscosity epoxy systems.

The impregnation is colourless and is intended to work its way into the concrete surface's pores and seal them. At the same time, the loose cement and sand grains in the surface are bonded. The wear strength of the concrete surface is substantially increased, while the floor becomes more resistant to chemicals. Spilled oil can, for example, be easily wiped away because it does not force its way into the concrete. Sealing leaves a tougher surface film that further increases the resistance and the mechanical properties. It can be applied both pigmented and non-pigmented.

• Thin layer coatings

The next category of coatings is thin layer coatings. Coatings of this type vary in thickness from about 0.3 mm to 1 mm. They normally contain hard filler to increase wear resistance.

This type of coating is primarily suitable for floors where loads are constituted by pedestrian traffic and light wheeled traffic in, for example, shops, warehouses, schools, hospitals, laboratories, etc.

• Self-levelling coatings

A very common floor coating in industry is self-levelling flooring screeds.

These are applied in layer thicknesses from 3 to 5 mm. They withstand considerable mechanical and chemical stress. The binding agent content is relatively high (about 35%) and the remainder is made up of quartz sand of well-suited grain size and pigment. Self-levelling coatings provide completely level, seamless and poreless floors, which among other things, have shown to comply with the high demands of hovercraft traffic.

Coatings based on epoxy normally have a compression strength that significantly exceeds concrete's. With heavy point loads, the underlying concrete can be pulverized, thus detaching the coating and resulting in damages. To avoid this, the thickness of the epoxy coating is increased so that the load is distributed over a somewhat larger concrete surface. Experience has shown that 3 mm is the thinnest coating for which one can expect load distribution. This is why coatings of 2 mm hardly ever occur. See "Necessary layer thickness".

• Epoxy concrete

When it comes to very large mechanical stress, coating is performed using so-called epoxy concrete. This is a high-fill epoxy mortar that is applied like concrete in layers of about 10 mm and above. The binding agent content is low, normally about 15%, and the filler consists of quartz sand with carefully determined grain distribution.

The low binding agent content entails that the linear coefficient of thermal expansion approaches that of concrete. This is important in the avoidance of stresses in the boundary layer to the concrete during temperature changes.

To achieve the highest possible strength, this type of coating is lightly vibrated. This is achieved by rendering with subsequent smoothing.

Epoxy concrete is used for many types of castings, for example, underpinning of rails and heavy machinery beding, transitions between bridge decks and roadways, gravel courses, loading docks, truck-ways and ramps.

• Concrete sealing

Concrete that is subjected to moisture, frost and air pollution is eventually damaged. The damage process is usually relatively slow, but on bridges the process most often occurs significantly faster. This can be explained by a bridge being subjected to several degrading forces, such as settling, drying, heat, cold, vertical movements because of traffic, and not the least, chemical stresses in the form of acid rain (pH value of rain can in some cases be as low as 2) and salting. See the chapter "Concrete and air pollutants". Damages that arise from salting are evident by de-scaling of thin layers of concrete. The risk for damage is greatest when the concrete contains water, as shown by damages being greatest where water drainage is worse. The reason for the salt's degradation capacity is probably of a physical nature. When salt melts ice, a substantial temperature drop occurs. For example, it can be mentioned that 33 grams of sodium chloride (common salt) that is spread over 100 grams of snow produce a temperature of -20°C, and a mixture of 140 grams of calcium chloride and 100 grams of snow produces a temperature of -55°C. Additionally, it is well known that a salt solution has a lower freezing point than regular water.

Of these known facts, one can draw the conclusion that the following two factors are degrading:

Hydraulic pressure and formation of ice crystals

Hydraulic pressure occurs when the ice crystals in the capillaries expand and force away unfrozen water so that it pushes a flow through the part of the concrete that is not frozen. High porosity and fast freezing can produce very high pressure.

The other factor is the formation of ice crystals. When ice is formed in a cavity, it has the property of attracting water from non-frozen areas as soon as the temperature in the cavity falls beneath the freezing point. In this way, the ice crystals grow and expansion and bursting effects occur, especially in concrete with low porosity. The forces of the two mentioned factors can easily exceed the concrete's tensile strength, thus resulting in damages. To counteract or prevent damages of the above-mentioned type, the concrete must be sealed against the entry of water, and additionally, free water in the concrete must be permitted to drain. This means that the sealer should be watertight and open to diffusion.

• Glue

As glue, the epoxy plastics have many application areas. Wood, metal and stone materials can be successfully glued to one another or to concrete. The epoxy plastics' high tensile strength and adhesion make them suitable for anchoring bolts and cables in concrete and rock. Glue based on epoxy is solvent-free and therefore has very little shrinkage. Based on the materials that will be glued and the glue location, one should select glue with the right elasticity, viscosity and hardening time. If the glue joint is subjected to chemicals, consideration should be taken to this. For more information, see the chapter "Gluing".

• Reinforcement of concrete constructions

Thanks to the epoxy glues' capacity to absorb considerable tensile and shearing stresses, it is possible to reinforce concrete constructions, for example, a bridge deck, so that they can withstand heavier loads.

The method involves gluing steel plate or carbon fibre to the concrete to increase the reinforcement area. It is possible to reinforce for both bending forces and shear forces.

The epoxy glue must have the right properties both in regards to consistency and strength for the glue joint to be able to transfer the forces to the applied reinforcement. The method of strengthening bridges has been adopted by the Swedish National Road Administration and is generally used to increase the bearing capacity of a large part of the bridge structure.
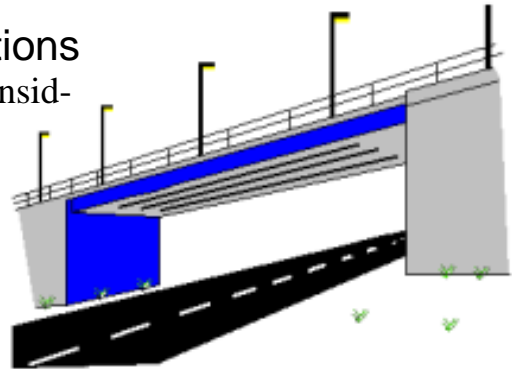
• Gluing of new concrete to old

A very interesting application area is the gluing of fresh concrete to hardened old and new concrete. It is a known fact that the adhesion of concrete to concrete, and concrete to rock is relatively poor; breakaway often occurs.

To avoid this, especially composed epoxy glues can be applied to the hard concrete that is to be covered; directly after gluing, the fresh concrete is cast.

The epoxy glue is designed so that the hardening time is longer than the concrete's, causing a gluing-together of the concrete surfaces to occur. Glue of the latter type shall contain filler that prevents an all too powerful penetration of the glue; moreover, it may not contain solvents.

Concrete that is cast to a glued surface shall be kept dryer than normally because no water may be drawn into the underlying concrete.

• Repair material

As repair material, the epoxy plastics are used for repairing holes and damages in the form of putty, repair paste and epoxy concrete. Examples of damages include pot-holes, impact damages, salt damages, damages from component production and concrete pile damages. Another application example is as sealing material around fixtures, such as around railing posts.

- Injection

Another special variant of gluing with epoxy plastic is injection into cracks and breakaways in concrete and rock. The method involves pumping in low-viscosity epoxy plastic in the cracks. The plastic thus glues together the separated surfaces. There is much that speaks for a cracked construction being repaired, namely:

1. Cracked concrete cannot distribute the load it was designed for.
2. Cracked concrete easily further degrades when subjected to freezing.
3. Corrosion to reinforcement occurs.
4. Pure leakage considerations.

Injection is addressed in detail in the chapter "Application and function".

- Lamination

In construction and civil engineering works, lamination with epoxy and various fibres, primarily fibreglass also occurs. Examples of use are interior coatings in chemical tanks and renovation of sewer pipes.

Electrical and electronics

As shown in the figure, the largest application area for epoxy is electrical and electronics. Epoxy's electrical insulation capability in combination with low moisture effect makes it suitable for the manufacture of circuit boards that are found in most devices, such as TVs, computers, cameras, etc. Epoxy is also used for components such as capacitors, diodes and transistors.
Epoxy is even used for embedding devices to protect against moisture or other aggressive environments.

Aircraft

In the aircraft industry, epoxy is primarily used as a laminate. The strength of carbon fibre epoxy laminate, in relation to weight, is very high in comparison to steel and aluminium alloys. The weight savings gained entail substantial benefits.
Model airplanes used in competition are often manufactured in epoxy laminate, and details such as propellers, in carbon fibre and epoxy.

Automotive

In the automotive industry, epoxy is primarily used as structural glue and thus replaces welding. These epoxy glues are of the single-component type, i.e. the hardener is mixed in the glue. Hardening subsequently occurs in a few seconds at high temperature. In the automotive industry, epoxy is also used for manufacturing press tools for sheet metal in the production of new car models. Extreme racing cars are as a rule, manufactured in epoxy and carbon fibre.
Once again, it is strength and low weight that is important.

Marine constructions

As marine constructions, all types of boats are naturally included. By tradition, most fibreglass boats are manufactured in polyester resin. When if comes to boats with high performance, for example racing boats, epoxy is a better alternative. The epoxy's strength and lower water absorption enables the laminate in the hull to be made thinner and consequently lighter.

Epoxy is used to a large extent to prevent water absorption in boats made of polyester resin. Water absorption in polyester plastic can lead to hydrolysis, i.e. degradation. A layer of just 0.3 mm epoxy prevents water from forcing its way into the polyester plastic.

On oil platforms, epoxy is used as protective coating on steel, both as a strong floor coating and as advanced corrosion protection.

Powder

Powder in this context refers to high molecular epoxy resin and hardener that are ground together. This powder can then be sprayed on a heated surface, where it melts and hardens to a coloured film. Examples are washing machines and corrosion shielded reinforcement bars.

Packaging and strapping

The interior lacquer in, for example, tin cans, is often epoxy lacquer. Freedom from pores and chemical resistance characterise such lacquers.

Miscellaneous

Under this heading, many things can be included. A very rapidly growing area of application is in the manufacture of propeller blades for wind power plants.
Epoxy is used to a relatively high degree in the manufacture of moulding tools. Examples of such manufacture can be sheet metal pressing, polyurethane casting, RTM, vacuum forming, injection moulding and blow moulding.

Such tools are used both in mass production of parts and for quick production of prototypes.

Example of mould manufacture
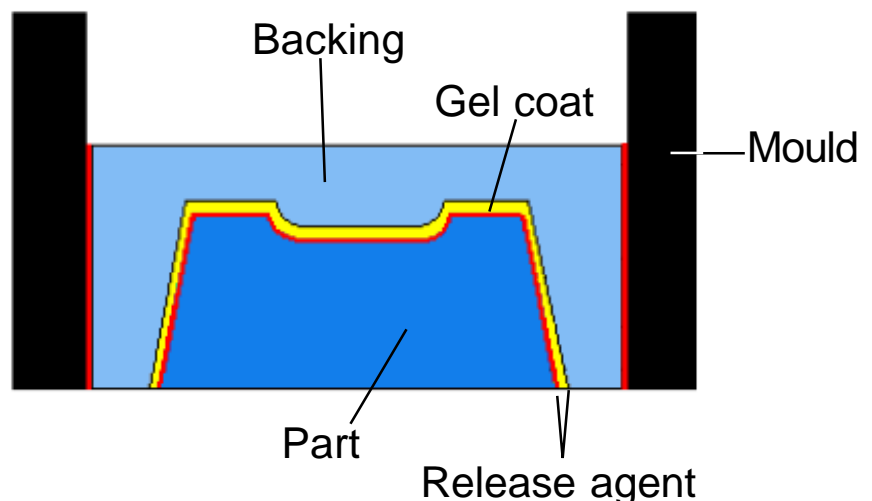
Surface preparations

To attain satisfactory results with a coating, it is not enough with a technically perfect product. Surface preparations, surface temperatures, moisture conditions and concrete strength are factors that are of very great importance. All contaminations on a surface have negative effects on adhesion. The surface that is to be coated must be strong enough to hold a coating in place. Furthermore, it can be disastrous to apply a diffusion-tight coating on a concrete substrate in which moisture wanders towards the surface. The temperature must naturally be high enough so that hardening takes place within a reasonable time.

Substrate's surface strength

Concrete and similar cement-based products often constitute the substrate for coatings of epoxy plastic. The strength of these primarily depends on the composition, but the application and the conditions during the application can have a major effect on the upper layer's tensile and compression strength. One must keep in mind that concrete and epoxy plastic have different properties in regards to, for example, coefficients of thermal expansion and modulus of elasticity. When heating or cooling a floor, the epoxy coating moves significantly more than the concrete. Stress occurs in the boundary layer. If the substrate does not have sufficiently high surface tensile strength, the stress can cause the coating to detach. Practical tests have shown that a concrete or cement-based substrate needs a surface tensile strength of at least 1.5 MPa (about 15 kp/cm^2) to be able to retain a coating. A normal floor concrete holds about 3 MPa.

Cement skin, also called laitance layer, has a tensile strength down to 0.1 MPa, and must always be removed prior to coating. This is best accomplished with steel-ball blasting or grinding.

One can even use diluted hydrochloric acid (10–20%) to remove the cement skin. The method is quick but entails certain disadvantages; machinery and iron objects in the area rust quickly in air containing hydrochloric acid. Furthermore, the salts that form during the hydrochloric acid's influence on the concrete must be removed; this is done with high-pressure water rinsing and brushing. One must check that the concrete surface after rinsing has a neutral or weakly alkali reaction; test with pH paper. If there are cracks in the concrete, the hydrochloric acid can force its way down and cause rust formation on the reinforcement. Another disadvantage is that one thoroughly wets the surface and must therefore wait with coating until the surface is dry.

The tensile strength can only be determined through onsite measurement. The method used is called the **pull-off** method, and involves measuring the force that is expended to pull off glued dollies.

A suitable instrument is an Elcometer 106 with the 0–3.5 MPa scale. The procedure is as follows:

So that the dolly is not glued askewed in relation to the instrument's pulling angle, a **NM Centring unit** shall be used. The centring unit consists of a steel ring and a rectangular plexiglass sheet with a track.

Place the steel ring on the cleaned concrete surface. Place a dolly in the track on the plexiglass sheet. Place the sheet on the ring so that the sides align with the ring's periphery. The dolly shall be possible to move back and forth in the track without touching the concrete surface.

Lift the sheet with the dolly. Blow the concrete free from dust. Apply glue to the dolly. Make sure that the dolly is pressed as far as possible into the track. Place the sheet on the ring so that the edges align with the ring's periphery. Push the dolly so that excess glue is pressed out. The dolly now rests on the plexiglass sheet.

When the glue hardens, the sheet is removed. Take away the glue excess that is beyond the dolly with a hole saw. Slide the Elcometer's grab unit onto the dolly and adjust the ring so that the outer part of the Elcomenter's pads align with the ring's periphery. Place the scale's release indicator at zero.
Hold the instrument in place with one hand and softly turn the knob. Read the value when the release indicator stops.
A test should always encompass at least five dollys.
Note that other instruments and other measuring methods can result in deviating values.

Substrate's degree of cleanliness
All contaminants on a surface negatively affect adhesion. Commonly occurring contaminants are dust, oil, grease and chemicals. Dust on the surface, for example, constitutes a block for the epoxy plastic in makings its way down into the concrete pores where it can anchor itself. It must be removed and this is done through powerful vacuuming; sweeping the surface with a broom is insufficient.

Grindings from concrete grinding can be difficult to remove by vacuuming. Water rinsing can be necessary to clean the surface.

If the concrete is contaminated with machine oil, grease or similar substance, it can be removed with an emulsifying agent. Thinner and ligroin, however, may not be used because these agents only dissolve the oil and spread it over a larger surface or deeper down into the concrete. After emulsification, the surface shall be rinsed with water.

If oil has forced its way deep into the concrete, it can be necessary to mill the surface layer. Animal and vegetable oils can be removed by washing with 10% caustic soda; the oil is saponified and becomes water-soluble.

Metal surfaces that shall be coated must be free from oil, grease, dust, rust, oxide scaling, etc. The best way to clean metals is by sandblasting. If the surface is oily, it can be necessary to wash with solvent, such as thinner or toluole prior to sand-blasting. A freshly blasted surface is very quickly attacked by humidity and oxygen; the coating shall therefore be performed as soon as possible after sandblasting is completed. If sandblasting cannot be performed, one must grind the surfaces with a grinding disk; steel brushing should be avoided.

Stainless steel requires special primer.

Concrete surface's degree of moisture

After construction, concrete contains a surplus of water. The amount of the surplus depends on the concrete quality. It can generally be said that it takes a very long time for surplus water, which is also referred to as construction water, to dry out of a concrete construction. The concrete is considered dry when its relative humidity is equal to the surrounding air's relative humidity. The drying time can in some cases be one year.

In wet concrete, the water rises capillarily through the concrete's pore system, up towards the surface.

This process does not cease when one applies a diffusion barrier. Because it takes a relatively long time for the epoxy plastic to harden, the water will concentrate in the concrete-epoxy boundary layer. Theoretically, it is enough with a water film of 5 angstrom ($5 \cdot 10^{-7}$ mm or 0.5 millionths of a millimetre) thick for adhesion to fail. This applies to all diffusion-tight materials that are intended to adhere to a substrate. Concrete that is dry to the moisture balance can be coated with a diffusion-tight coating without problem.

Concrete that has not dried to the moisture balance can only be coated with a material that permits water vapour to pass during the hardening process. Such material is called diffusion-open. The amount of water vapour that can pass during a specific time is dependent on the layer thickness.

By combining a diffusion-open epoxy plastic with a diffusion-tight, it is possible to apply tight coatings to wet substrates.

The concrete's degree of moisture can be measured with a hygrometer, but it is not always necessary to know the exact measurement value. A covered hygrometer on the concrete substrate provides a quick indication of if water is wandering towards the surface and evaporating. This check is made by placing a bit of polyethene foil on the floor. The hygrometer is placed above the plastic foil and remains there for about 15 minutes to adjust itself to the floor temperature. The hygrometer is now read and the value noted.

The hygrometer is thereafter placed under the plastic foil and the edge sealed with, for example, masking tape. After an hour, the hygrometer is read and the value compared to the first. If the concrete's moisture is in balance with the air's, the second value is the same as the first.

Temperature

Before coating with epoxy plastic, the surface temperature must be checked. Temperatures between +13 and +25°C seldom lead to problems.

For temperatures under +8°C, some form of heating should be applied; under 4°C hardening is so slow that one should avoid treating with epoxy. Aqueous emulsified epoxy generally requires at least +10°C at the substrate in combination with good ventilation.

A factor to include in calculations is that the air in the concrete pores expands as the temperature rises, for example, in sunshine or under substantial heating. This can cause blistering.

It is advantageous to coat the concrete when the temperature is decreasing.

If there is risk that a coating or similar covering with epoxy plastic will be substantially cooled during the hardening process, as is the case with night frost, heat shall be applied. It is namely so that a reaction that stops can be difficult to restart.

Wood and wood fibreboard

Epoxy plastic has very good adhesion to wood, but one must take into consideration that wood is a living material and moves considerably in comparison to other materials. While wood swells when subjected to moisture, epoxy plastic does not, which gives rise to powerful stresses. On wood fibreboard, however, coatings can be applied with good results.

Mixing

All epoxy products are two- or multiple-component products. As described previously, an epoxy resin must be mixed with a hardener to become a plastic. The reciprocal amounts of resin and hardener are carefully determined. They vary of course from case to case, depending on the type of resin and hardener, but in each individual case, the specified mixing ratios may not be changed.

What is supposed to happen is a chemical reaction between the oxygen in the epoxy resin and the hydrogen in the amines in the hardener. This requires that the hardener be mixed very carefully with the epoxy resin so that all hardener molecules come in contact with the epoxy molecules. They shall hook onto one another to form the plastic's large molecule.

Schematically, one can draw it like this:

Epoxy molecules' bonding to a hardener molecule
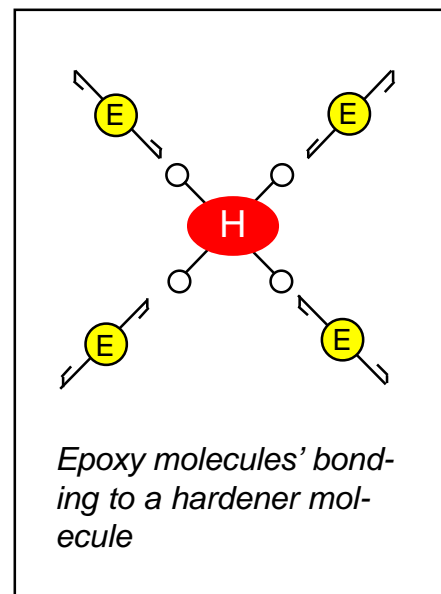
The circles with two hooks are epoxy molecules and the circle with four rings is a hardener molecule. If not all of the hooks fasten in the rings, there will be no complete epoxy plastic molecule.

The glue, coating or whatever it is, would be weakened, soft patches would arise, and strength and chemical resistance would decline.

If the relation between the epoxy resin and hardener (mixing ratio) is faulty, it does not help with perfect mixing. The excess of one or the other component would always be non-reacted.

This would naturally degrade the epoxy plastic's physical properties. The importance of using kit-packaged epoxy and hardener cannot be over emphasised. If the components are weighed at the factory with a functioning quality system, the risk for faulty blend proportions as good as non-existent.

Should a kit package be split, despite all, it shall be done with the help of a scale with sufficient accuracy. The mixing ratio, or mixing proportions, indicated in weight units shall be printed on the package. Splitting packages using volume measurements can cause very serious faults.

Small amounts, that is to say up to about 1 kg, can be mixed by hand with a mixing paddle that must be rectangular.
Suitable paddle dimensions are approximately 10 x 40 x 400-500 mm.

To try to mix the epoxy with a round rod, screwdriver or a piece of reinforcement bar is doomed to failure. Large amounts are impossible to satisfactorily mix by hand, and thus require electrical or pneumatically powered mechanical mixers, for example a low-speed drill with splashguard and suitable mixing wings (see figure). Epoxy concrete and other masses with low binding agent content can be mixed in a concrete mixer or paddle mixer. Epoxy resin and hardener shall always be carefully mixed before filler is added.

Example of mixing wing attachment

Before mixing the epoxy plastic, it can be necessary to temper the components. This can be done with hot air or in a water bath.

Open flame may not be used.

It is best to store the products in heated indoor areas. At worksites, there are often various types of epoxy and hardener. Always sort them by type to avoid mistakes. At larger worksites, set up a mixing station where one person is responsible for mixing; this is the most important part of the work process.

Adhesion

For all painting and coating work, it is important to ensure that moisture does not condense on the substrate while work is underway. Water in the boundary layer can prevent adhesion between the epoxy and substrate. Condensed water is called dew in everyday language.

Water vapour is soluble in air up to a certain level that depends on the air's temperature. The warmer the air, the more water vapour it can dissolve.
When the air is saturated with water vapour, one has reached the saturation vapour content.
At + 20°C, for example, the air's saturation vapour content is 17.3 g / m^3. This can also be expressed as the air's relative humidity (RH) being 100%.
Air that at + 20°C contains 10.4 grams of water per cubic metre thus has a relative humidity of (10.4 / 17.3) x 100 = 60.1%.

When air that contains a certain amount of moisture is cooled, it will eventually reach the saturation vapour content. This temperature is called the dew point.
By measuring the air's relative humidity using a hygrometer and with the aid of a dew point table, one can establish the dew point for the current air temperature.

In the table, one can see, for example, that the dew point at an air temperature of +20°C and a relative humidity of 60% is +12°C, i.e. if the temperature falls from +20°C to +12°C, dew forms. To ensure that dew does not form on the surface to be coated, it should have a temperature of at least 3°C above the dew point, or +15°C in the above example.

Another phenomenon that can influence adhesion between hardened epoxy and a new layer of epoxy is the epoxy hardener's capacity to form insoluble amine carbonates and amine carbamates.
This occurs during the hardening process upon the amines' reaction with the air's content of carbon dioxide (CO_2) and water. Different hardener types have different susceptibilities to carbonation. Pure amines have, for example, greater susceptibility than amine adducts. Low hardening temperature also benefits carbonate formation.
To ensure good adhesion, it is necessary to remove any carbonate film. It can be difficult to determine if an epoxy layer is coated with a carbonate film or not; it is namely not visible to the naked eye.
Sanding or rather flatting is often sufficient. It can often suffice with priming with aqueous emulsified epoxy since the amine carbonate is somewhat water-soluble.

Dew point table

Air temperature	Dew point in °C at relative humidity of								
°C	50%	55%	60%	65%	70%	75%	80%	85%	90%
5	-4.1	-2.9	-1.8	-0.9	0.0	0.9	1.8	2.7	3.6
6	-3.2	-2.1	-1.0	-0.1	0.9	1.8	2.8	3.7	4.5
7	-2.4	-1.3	-0.2	0.8	1.8	2.8	3.7	4.6	5.5
8	-1.6	-0.4	0.8	1.8	2.8	3.8	4.7	5.6	6.5
9	-0.8	0.4	1.8	2.7	3.8	4.7	5.7	6.6	7.5
10	0.1	1.3	2.6	3.7	4.7	5.7	6.7	7.6	8.4
11	1.0	2.3	3.5	4.6	5.6	6.7	7.6	8.6	9.4
12	1.9	3.2	4.5	5.6	6.6	7.7	8.6	9.6	10.4
13	2.8	4.2	5.4	6.6	7.6	8.6	9.6	10.6	11.4
14	3.7	5.1	6.4	7.5	8.6	9.6	10.6	11.5	12.4
15	4.7	6.1	7.4	8.5	9.5	10.6	11.5	12.5	13.4
16	5.6	7.0	8.3	9.5	10.5	11.6	12.5	13.5	14.4
17	6.5	7.9	9.2	10.4	11.5	12.5	13.5	14.5	15.3
18	7.4	8.8	10.2	11.4	12.4	13.5	14.5	15.4	16.3
19	8.3	9.7	11.1	12.3	13.4	14.5	15.5	16.4	17.3
20	9.3	10.7	12.0	13.3	14.4	15.4	16.4	17.4	18.3
21	10.2	11.6	12.9	14.2	15.3	16.4	17.4	18.4	19.3
22	11.1	12.5	13.8	15.2	16.3	17.4	18.4	19.4	20.3
23	12.0	13.5	14.8	16.1	17.2	18.4	19.4	20.3	21.3
24	12.9	14.4	15.7	17.0	18.2	19.3	20.3	21.3	22.3
25	13.8	15.3	16.7	17.9	19.1	20.3	21.3	22.3	23.2
26	14.8	16.2	17.6	18.8	20.1	21.2	22.3	23.3	24.2
27	15.7	17.2	18.6	19.8	21.1	22.2	23.2	24.3	25.2
28	16.6	18.1	19.5	20.8	22.0	23.2	24.2	25.2	26.2
29	17.5	19.1	20.5	21.7	22.9	24.1	25.2	26.2	27.2
30	18.4	20.0	21.4	22.7	23.9	25.1	26.2	27.2	28.2

Relationship between relative humidity, air temperature and dew point

Application and function

The epoxy plastics have, as seen, many application areas and each area requires special application methods. The final results are always a function of material properties, the substrate's properties and execution. Application techniques will now be described for some of the application areas addressed in this book.

Impregnation

The simplest treatment that is performed on concrete substrates is impregnation with low viscosity epoxy plastic. The purpose is to strengthen the concrete's surface layer, both mechanically and durability-wise. As epoxy material, aqueous emulsified epoxy, solvent content epoxy or non-solvent epoxy are used. The materials are always non-pigmented and without fillers.

Application is performed using rubber squeegees on handles. Suitable widths are 40–60 cm. The surface shall be saturated with epoxy plastic. To avoid shiny spots, it is appropriate to roll afterwards with felt rollers. For solvent and aqueous epoxy, good ventilation is necessary.

Priming

Concrete and other absorbing substrates that are to be coated shall always be primed first. The primer has several tasks. It shall saturate the concrete so that the binding agent from the coating does not vanish down into the substrate instead of strengthening the surface layer.

Furthermore, the primer's low viscosity makes for good wetting against the substrate, which is of primary importance for adhesion. If the primer is diffusion-open, it can stop the moisture flow from the substrate and thus make it possible to apply a diffusion-tight coating on a damp substrate.

Epoxy for priming can be solvent-free, solvent-bearing or aqueous emulsified. A solvent-free primer can be applied in ample coats and thus provide good fill of pores and voids. However, it is inappropriate to use this type on moist substrate if it is not diffusion-open.

Solvent-bearing primer has good penetration properties in porous substrates, but this also implies that the solvent forces its way down into the substrates. Because epoxy resin has very high solvent retention, i.e. the capacity to retain solvents, the risk is great that the solvent will be closed in when subsequent coatings are applied. When it comes to priming of non-absorbing substrates, such as sandblasted steel surfaces, it is often advantageous with a few percent of grease dissolving solvent. A solvent-free primer cannot even dissolve small amounts of grease. This means that, for example, fingerprints on a cleanly sandblasted surface can cause degraded adhesion if the primer is completely free from solvent.

The aqueous emulsified primer can generally be applied on both dry and damp substrates. The substrate's temperature and the air's relative humidity must be checked to ensure that the water in the epoxy primer can evaporate. As a rule, +10°C applies for the substrate and a maximum of 80% relative humidity in the air. Aqueous emulsified epoxy cannot be applied in thick layers. The primer material is applied with rollers or is spread with rubber squeegees and rolled afterwards. It is often necessary to repeat the priming to achieve the desired purpose.

Solvent-free and solvent-bearing epoxy primer shall always be covered as soon as possible. In practice, this means within 12–24 hours. If the primer layer is not covered within 6–7 days, there is great risk for poor adhesion between the epoxy layers. This is related to the epoxy's carbonation. An aqueous dispersed primer generally contains such small amounts of free amines that carbonation does not occur. This type of primer can therefore be covered up to one month after application, as long as the surface is cleaned from any contaminants.

Thin layer coatings

Thin layer coatings refers here to pigmented epoxy plastic for coatings of about 0.3–1 mm.

These coatings are intended to provide a homogenous, continuous film that protects the substrate from wear and chemicals. The surface can be made smooth or include anti-skid properties. The material consumption must be adapted to the substrate's surface profile to achieve a specific minimum layer thickness.

Thin layer coatings of 0.3 mm can be aqueous emulsified/dispersed and are normally applied in two coats using rollers. This type of coating can be pervious for water vapour. Anti-skid in the form of quartz sand or glass beads can be sprinkled over the first layer before it hardens.

Solvent-free coatings can be applied with rollers up to about 0.5 mm. Thicker layers are applied with trowels. Anti-skid can be sprinkled on the unhardened coating.

Both of the described types of thin layer coatings can be lightly sprinkled with coloured flakes to give the surface a decorative appearance.

Flaked surfaces shall always be given a lacquered coat.

If the coating is intended to be diffusion-open, the lacquer coat must also be diffusion-open. The surface lacquer is applied with felt or mohair rollers in a uniform coating.

Screed coatings

Screed coatings of epoxy plastic encompass many different types. A common denominator is that they contain epoxy as the binding agent to mineral filler. The filler is often quartz sand of various grades.

Screed coatings are easily divided into three types:

1. Self-levelling screeds
2. Dry mortars
3. Toploaded screeds

A self-levelling epoxy screed consists of about 35% binding agent and the rest filler and pigment. It is commonly applied in layer thicknesses of 2–4 mm. The filler shall be graded so that the granulate maximum makes up about 1/3 of the layer

Self-levelling screed with graded filler

thickness. Furthermore, the filler shall be evenly distributed from the bottom to the surface after the compound has hardened. The binding agent content in self-levelling screeds is sufficient for each filler granulate to be surrounded by binding agent. They shall thus be considered as completely tight.
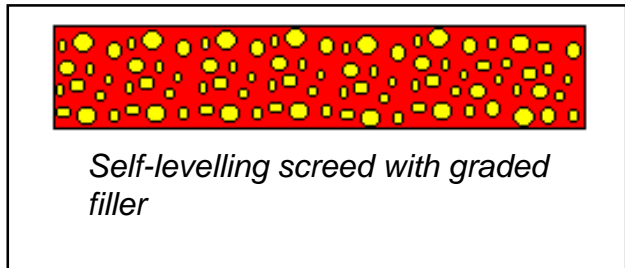
Application is by trowel, pin rake or special applicator. After application, the surface is normally treated with a spiked roller to puncture any air bubbles. Edges shall be formed with an approximately 5 mm deep groove in the

Spiked roller, special applicator and trowel

substrate. Anti-skid material can be sprinkled over the compound before it hardens.
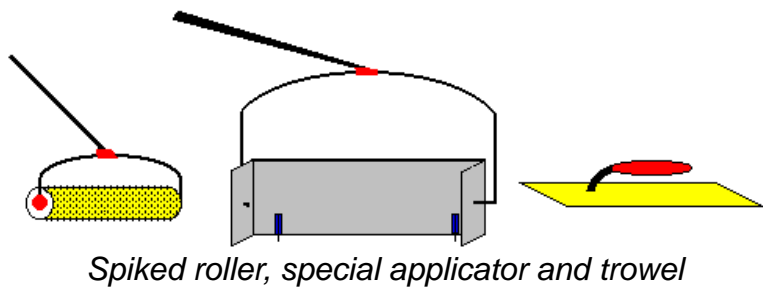
Mortars consist of epoxy binding agent and quartz sand. The quartz sand is often coloured to give the coating a decorative appearance. The binding agent content is low,

Lacquer layer

Mortar

commonly between 14 and 15% by weight.
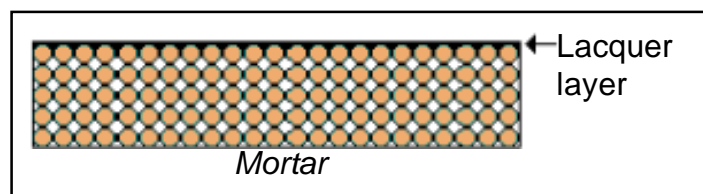
Mortars are normally applied in layer thicknesses of 3–6 mm. The low binding agent content is not sufficient to fill voids between the grains of sand, and coatings of this type cannot be considered as entirely tight. The application of mortars is either by rendering on laid strips or with a hand-drawn trowel with adjustable gaps. After spreading, the surface is finished with a straight tool or helicopter. The day after the compound has hardened, the surface is sealed with an epoxy lacquer.

Toploaded screeds are built up by dry, often coloured quartz sand being spread over an epoxy binding agent. Depending on how the coating is built up, the final results can be considered as tight or non-tight.

Mortar with sand bed ← Lacquer layer
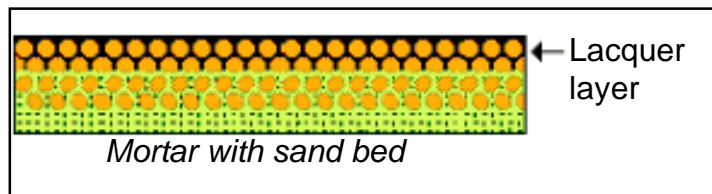
If the binding agent is unfilled epoxy that is rolled on the substrate, it will be capillarily absorbed by the sand. The compound then attains a porous structure. If the epoxy binding agent instead contains filler that quickly separates after spreading, a bed for the sprinkled-in sand is formed. After saturation, the free sand thickness on the surface consists of about 1.5–2 grains.

Such a thin open structure can be easily saturated with surface lacquer and the coating can be considered as completely tight.

The application involves an epoxy binding agent being spread in an even layer on the substrate. For systems with fillers, pin rakes or special applicators are used. Unfilled epoxy binding agent is applied with rubber rakes and finished rolled.

After laying the epoxy binding agent, sand is sprinkled on the surface to full saturation. Glossy spots may not occur. The day after, the excess sand is removed and the surface scraped with a steel blade on a handle to remove projecting grains of sand. After careful vacuuming, the surface is lacquered with epoxy. The lacquer is distributed with rubber squeegees and finished rolled.

This type of coating automatically attains built-in anti-skid.

The degree of roughness is regulated by the lacquer volume.

Normally, the coating is 3–5 mm thick.

Injection

To be able to inject epoxy plastic into cracks, one should have special equipment. There are several models of such devices.

Two common injection devices are shown on the following page. In some cases, one can get by with gravity, for example, when void injecting in floors.

It is essential that the devices have manometers.

Normally, pressure no higher than 0.03 to 0.3 MPa is required, and a hand pump can most often be used.

The procedure for injection is as follows:

The concrete surface is cleaned to a width of 10 cm on each side of the crack. The nozzles are glued with contact adhesive over the crack. The distance between the nozzles is determined from case to case. One can generally say that the distance shall be longer between the injection nozzles the wider the crack. The distance should not exceed 20 cm for a crack width of 0.5 mm and not exceed 50 cm for a crack of about 1.5 mm.

Epoxy putty is used to seal around the nozzles and over the crack between the nozzles. If it is a through-crack and the rear is accessible, the crack shall be sealed there too. All cracks that are connected with one another shall be equipped with nozzles. The only entry points to the crack or cracks are now via the nozzles. To check for

openings, dry compressed air is blown through. The injection plastic shall be as low viscous as possible. If the temperature in the concrete that is to be injected is very low (under 8°C), the viscosity of the injection plastic will increase as it cools and injection will go very slowly. In cracks under 0.2 mm, it may be impossible to press in the plastic. **Supplements of solvents may not be used!**

One commonly uses epoxy systems with long potlife.

The epoxy resin and hardener is mixed very carefully according to the specified mixing proportions. The mixture is poured into the injection container (if a hose pump is used, the suction hose is inserted into the epoxy mixture) and the discharge hose is connected to the lowest injection nozzle. The deeper the crack the slower the plastic is pressed in, i.e. the pressure shall be as low as possible.

Later, when the plastic emerges from the other nozzles they are sealed with

Manometer

Check valve

Pressure chamber
Protective coating with sight glass

Container for injection plastic

Injection equipment, pressure chambre model

plugs. Injection continues from the first nozzle as long as plastic forces its way into the crack. When no more plastic forces its way in, the hose is moved to the next pipe, and so on.
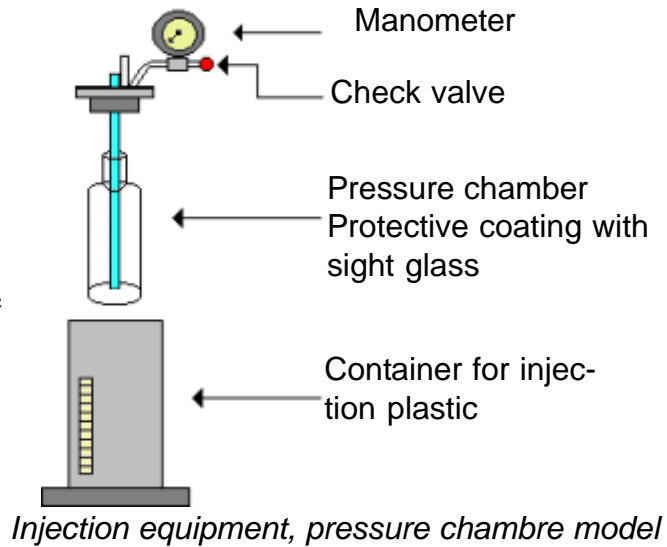
A metre-long hose is attached to the upper pipe and secured in the vertical position. Injection continues until this hose is filled. Pumping is then temporarily stopped. As the voids and micro-cracks are filled with plastic, the level in the attached hose falls. This is compensated with more injection plastic being pressed into the crack. In this way, work continues until the crack is saturated.

The nozzle and surface sealing remain for a day or so until the plastic has hardened. When injecting around beams in floors, one must be very careful with respect to pressure.

A pressure of 0.1 MPa produces a lifting force of 100 kN/m^2 (10 ton/m^2).

Manometer bracket

Manometer

Tap

Rotor housing

Pressure side, connected to injection nozzle

Clamp

Pumpstand

Suction side, inserted into injection plastic

Injection equipment, hose pump model
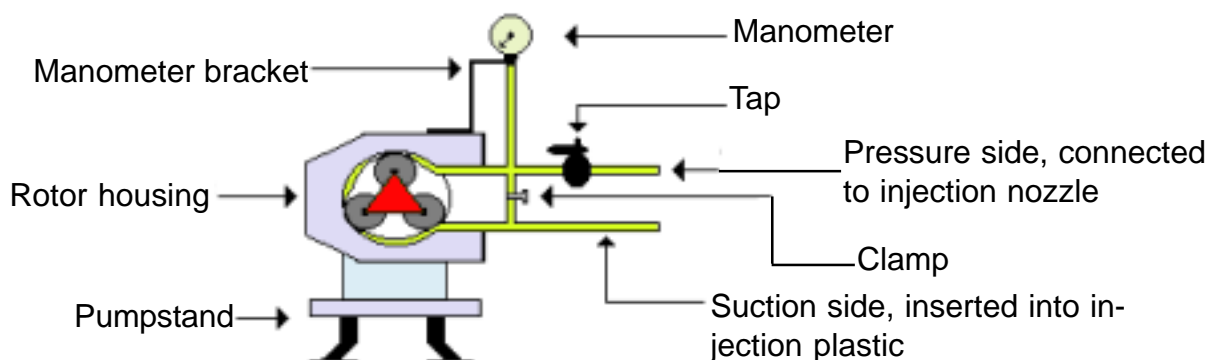
Gluing of new concrete to old

To attach new concrete to old, or to another substrate, epoxy plastic can be used in two ways.

The first method is a standard gluing, and is carried out so that the epoxy glue is evenly distributed over the surface to be cast to. Concrete is then poured over the unhardened glue. The glue shall be plentifully applied. The normal consumption is about 0.5 kg/m^2. The glue's open assembly time, i.e. the time available to cast concrete after the glue is applied, must be observed.

This time varies with the substrate's temperature. The concrete shall be kept somewhat drier than normal, since no water will be absorbed by the old concrete surface. The hardening time is relatively long for this type of glue.

The other method involves applying an epoxy binding agent on the old concrete. The surface is sprinkled with quartz sand to full saturation. The day after, the excess sand is swept away and casting can begin. This method is especially well suited for levelling mortar.

Repairs of corners, edges and surface damages

Generally, for all repairs and damages to concrete, one shall avoid feathering the repair material thickness to zero. This especially applies to floors with heavy loads. The reason for this is that the concrete has less compression strength than epoxy. With thin layers, there is a risk that the concrete can be crushed during the repair and new damage would thus occur. The procedure is therefore to cut a groove at least 3mm deep at the edge of the damaged area, and thereafter hew away a portion of the surface layer.

The repair material consists of epoxy putty or mortar of epoxy binding agent and quartz sand.

Damages to epoxy coatings are prepared in the same way with a cut groove. The repair is performed with the same material as the coating.
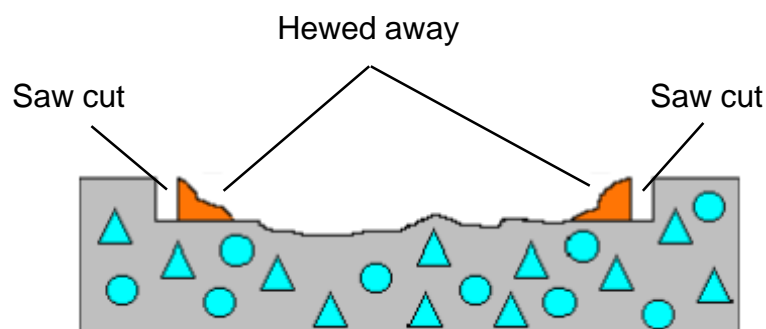
Lamination

Lamination means constructing something in many layers. Epoxy is used largely together with fibres of glass, carbon, aramid and polyester in laminate constructions. Such laminates are used alone, for example, in automobile chasses, boats and aircraft parts, as well as in conjunction with substrates such as steel or concrete for internal coating in tanks and cisterns.

The basic principle for all lamination with fibre and a matrix (for example, epoxy plastic) is that the matrix shall enclose each individual fibre in the fibre bundle. Each fibre bundle in a fibreglass weave contains about 400 fibres with a diameter of about 10 µm (1 µm = 1/1000 mm). The epoxy plastic must have good wetting properties and good adhesion to the fibres. To insure that air in the fibre bundles is removed, a rubber squeegee or short bristle roller is used to press in the epoxy.)

Various methods for manufacturing laminate are, for example, hand lamination, injection, prepreg, pultrusion and filament winding.

When several layers of weave will be used, one strives to work wet on wet until the full thickness is attained. The weave shall always be laid with an overlap of 5–10 cm. For multiple layers, joints shall be offset. Weaves have maximum strength in the fibre direction, which can in many cases be utilised.

When laminating on concrete or steel in a cistern, work begins on the walls. The weave is extended about 30 cm onto the floor. In the transition between wall and floor, a fillet shall be formed with epoxy putty so that the weave has a soft transition. All lengths shall be cut in advance. The laminating epoxy is applied to the wall with rollers. The weave is applied and worked with a rubber squeegee so that no air bubbles or creases remain. The surface shall thereafter be saturated with laminating epoxy.

When the lamination on the walls is finished and hardened, the joints are puttied with epoxy putty.

The weave that was run onto the floor is sanded free from loose strands and irregularities. The floor lengths are measured and cut so that they run a few centimetres from the wall. The first length is laid out on the dry bottom. The laminating epoxy is poured on the weave and distributed with a rubber squeegee. The weave shall be saturated immediately. The second length is laid with an approximately 10 cm overlap and the laminating epoxy is applied as before.

If two layers of weave are to be laid, it is best to split the first length of the second layer; this so that the overlaps will be offset.

Concrete sealing

Concrete that is subjected to aggressive environments must be protected. Epoxy plastic, due to its very high alkali resistance, is a suitable material for this purpose. An example of concrete in tough environments is a bridge where water, salt and air pollutants constantly affect unprotected concrete sections. One of the bridge sections that is protected with epoxy is the inside of the edge beam. A thixotropic epoxy is applied in two layers so that the thickness of the insulation is at least 0.5 mm.

Application is normally with brushes.

For all outdoor work, consideration must be taken to the weather. Temperature has a substantial influence on both the epoxy's hardening time and viscosity. Moisture, both in the concrete and in the air, can cause problems with adhesion and blistering. One shall ensure that the concrete has a temperature that is about 3°C over the current dew point. (See the chapter on adhesion for details.) The blistering that sometimes occurs before the epoxy has hardened often has its natural explanation and is grounded in purely physical laws. Upon heating of gases, these expand for each degree of increase with 1/273 of their volume at 0°C.

The pressure that arises in a gas mixture such as, for example, air and water vapour, is equal to the sum of the components' partial pressure. In concrete that has a void percentage of about 15%, the gases consist of air and water vapour. If one for simplicity's sake shall assume that the air in concrete is saturated with water vapour, the following applies:

If the volume of an air pore is set to 1 at 0°C, the gas volume increases to 1.09, i.e. 9% at a temperature increase to 20°C. If we set the volume to 1 at 20°C and raise the temperature to 40°C, the gas volume increases to 1.16 or by 15.6%. Concrete always has a certain porosity in the surface. This is especially apparent when sandblasting. If the pores are not filled with epoxy during application, there will be a thin film over the voids. A small temperature increase entails that the gas volume in the covered voids increases. Because the unhardened epoxy cannot withstand the pressure, blistering occurs.

To avoid blistering, keep the following in mind:

1. Avoid heating the concrete surface.
2. Preferably apply in the morning when the concrete is cool.
3. Avoid direct sunlight.
4. Try to fill the pores during application.
5. Keep epoxy cans out of direct sunlight. Raised temperatures entail shorter potlife with substantial temperature increases, and degraded wetting and adhesion as a result
6. Never thin the epoxy with solvent.

Detail design

Attachment to bearing wall

Wall covering, tile or wall matting is overlapped onto the foundation treatment by about 50 mm. The lower edge of the wall covering is sealed with silicon caulking for construction applications (not acetic acid based).
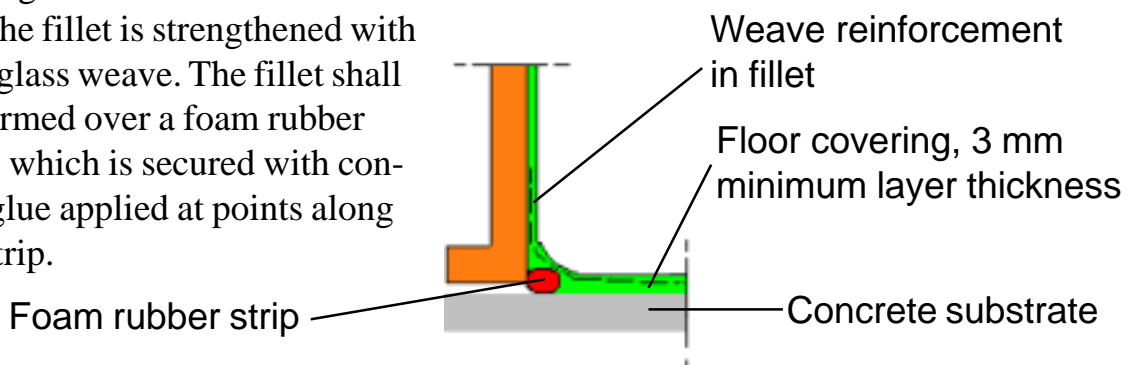
Wall matting

Tile

Floor covering, 3 mm minimum layer thickness

Concrete substrate
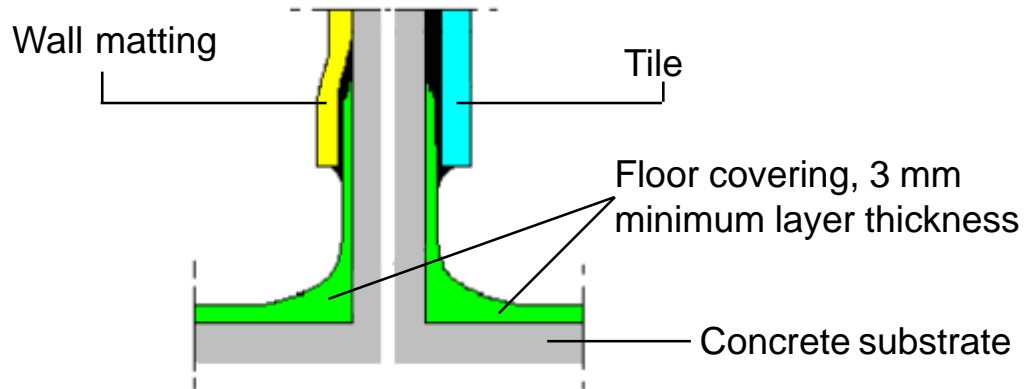
Foundation treatment

Wall colour in same colour as floor compound. Foundation height, 100–200 mm. Fillet formed with radius of about 30 mm using elastic epoxy putty.

Floor covering, 3 mm minimum layer thickness

Concrete substrate
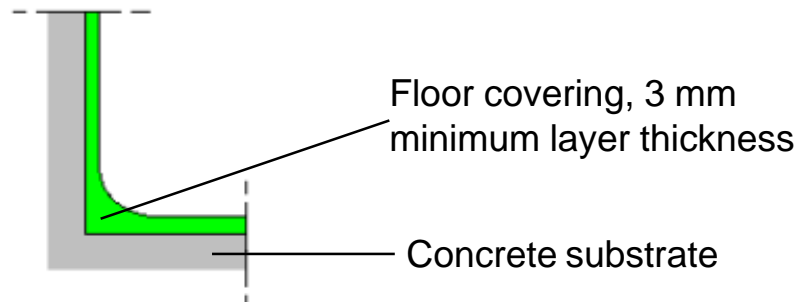
Attachment to non-bearing wall (e.g., cold store)

Procedure as with attachment to bearing wall with the difference that the fillet is strengthened with fibreglass weave. The fillet shall be formed over a foam rubber strip, which is secured with contact glue applied at points along the strip.

Weave reinforcement in fillet

Floor covering, 3 mm minimum layer thickness

Foam rubber strip

Concrete substrate

Attachment to free-standing, recessed wall (e.g., cold store unit)

Procedure as with attachment to non-bearing wall. Joint gap between wall and concrete substrate is sealed by pressing in sealing hose.

The fillet is formed over a foam rubber strip. The fillet radius is somewhat larger than with wall attachment according to the above.
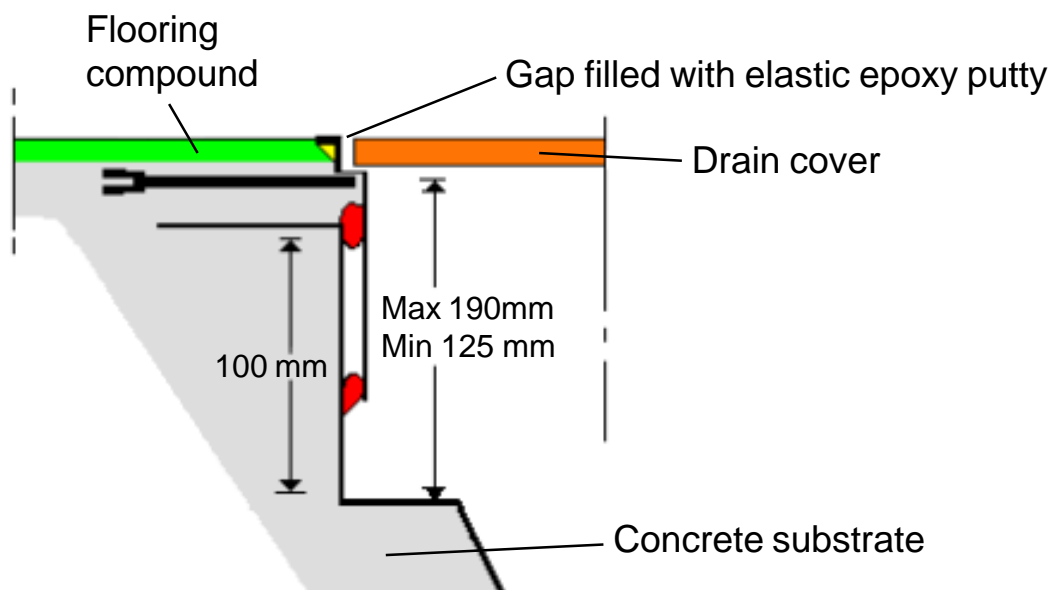Here, it is about 50 mm.

Weave reinforcement in fillet

Foam rubber strip

Floor covering, 3 mm minimum layer thickness

Concrete substrate
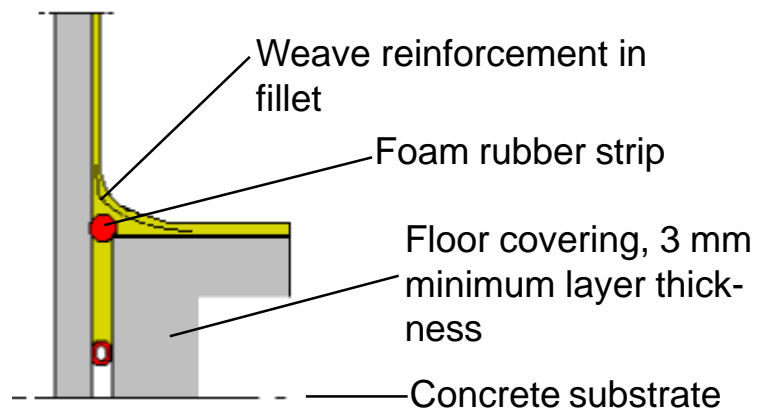
Attachment to floor drain that can be raised and lowered

These types of drains are used in institutional kitchens at, for example, large kettles. Before fitting the upper part of the drain, fill the gap around the upper part with elastic epoxy putty to ensure that the gap is completely filled. Make sure that the elastic putty covers the part of the drain edge to which the floor compound is attached.
For grouting of the upper part, the opening is sealed between the upper part and lower part by pressing in a sealing hose.
When grouting the upper part, grooves are made in the mortar that entail that the coating thickness is increased to 2 at 3 times **t** closest to the drain.
The increase in thickness is attained as with fixed floor drains of a length of about 400 mm.
The floor around this type of drain is normally sloped at 1:50 to 1:100 towards the drain, entailing that local sloping is not required. The gap opening between the upper part and lower part is sealed below after assembly with silicon caulking for construction applications (not acetic acid based).

Flooring compound

Gap filled with elastic epoxy putty

Drain cover

Max 190mm
Min 125 mm

100 mm

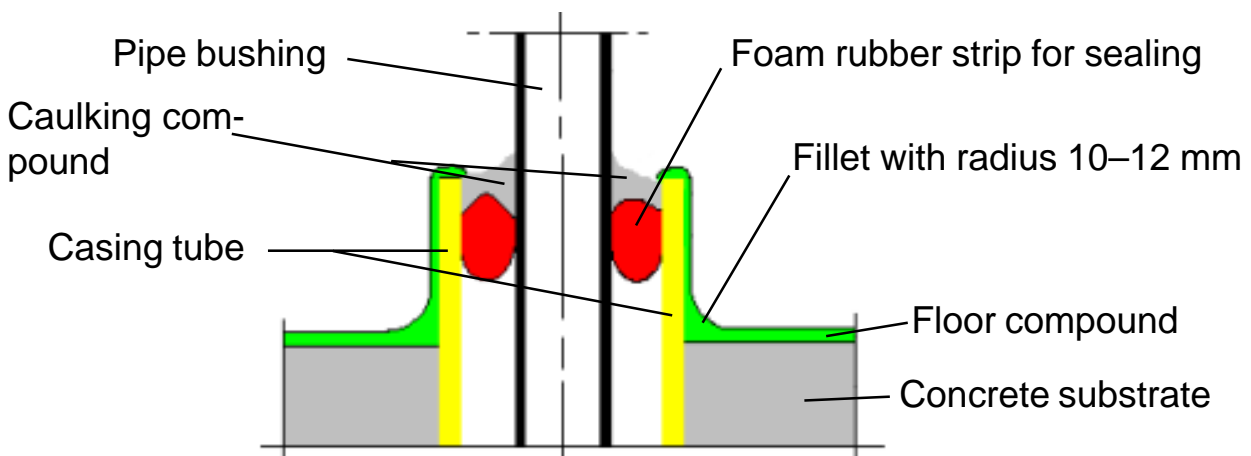Concrete substrate

Attachment to floor mats in door openings

Brass coping, 30 or 38 mm, is fully glued to the substrate with elastic epoxy putty.

Screws for securing of the coping are replaced with putty in that full sealing is desired.
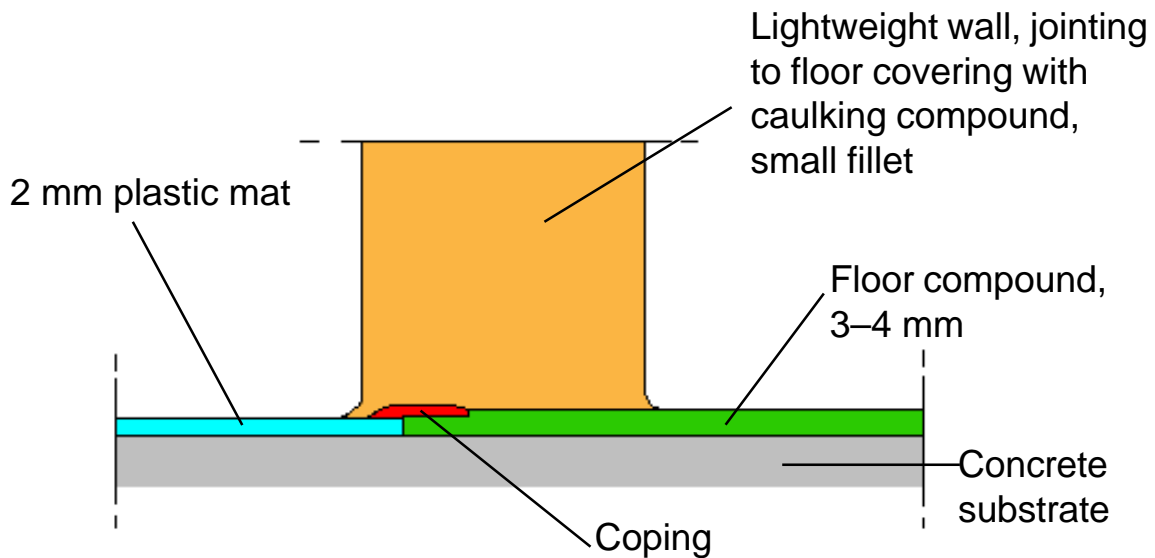
Attachment to casing tube for pipe bushing

The floor coating is attached to the casing tube with a fillet radius of 10–20 mm. The fillet is formed with elastic epoxy putty. Over the fillet and casing tube, and down onto the inside of the casing tube, a coating is applied in the same colour as the skirting, thickness 300–400 µm.

The seal between the pipe and casing tube is made with foam rubber and sealed with silicon caulking for construction applications (not acetic acid based).

Procedure for concrete substrate at floor drain

Choose floor drains with narrow, open edge collars, not drains with clamping rings of the type used for flooring with floor mat.

Choose stainless steel drains, not plastic-coated steel drains.

In rooms with level floors, the local slope is formed with a radius of about 500 mm in the sub-floor and floor coating. The slope for the sub-floor is somewhat steeper to permit space for the increase in thickness of the flooring from **t** to 2 at 3 times **t** within the slope radius.
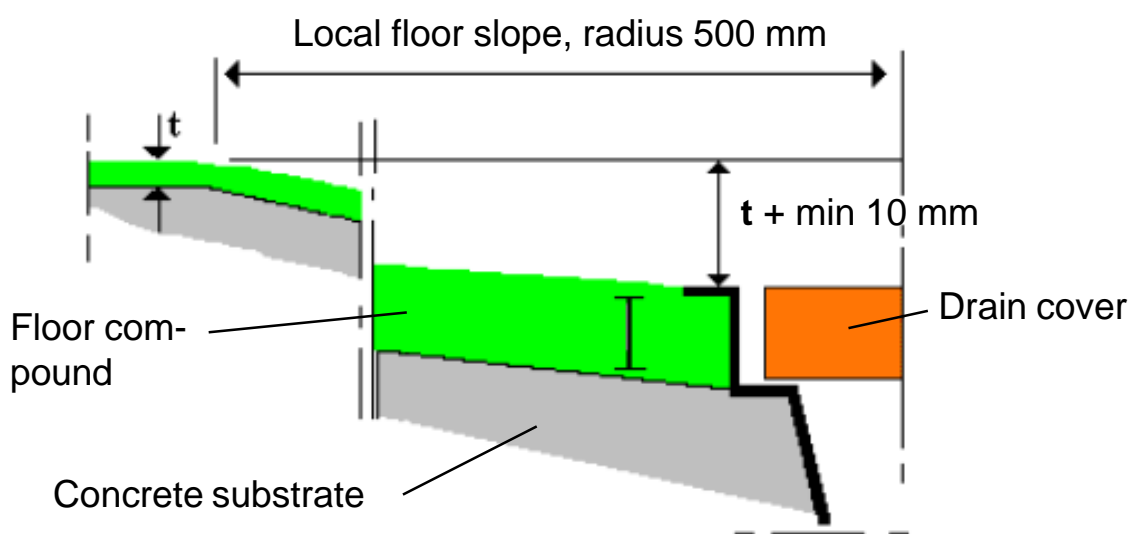
Fit the floor drain so that its upper edge is at least 10 mm beneath the level concrete substrate.
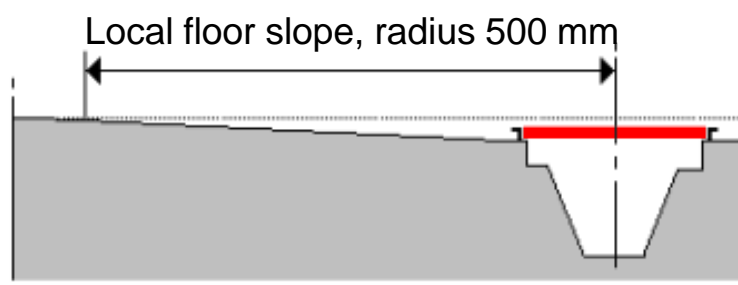
Leave sufficient space for thickness increase in the flooring adjoining the floor drain. For drains in floors with slopes, local sloping around the drains can be eliminated.

Construction of fillets

A fillet is the concave, rounded transition between, for example, walls and floors or in corners between the walls. Fillets are most easily constructed using a putty knife that is ground to the desired radius.

Fillets at transitions where one can expect movement are constructed with elastic epoxy putty; in other cases, hard epoxy putty can be used.

The technique involves laying an ample layer of putty in the angle and ensuring that it is well filled. The fillet is then formed by drawing the ground putty knife at a 90° angle to the fillet. Excess material that is pushed to the sides can be easily scraped away with a straight putty knife.

Material consumption can be calculated using the following formula:

$$m = 0{,}22r^2 \text{ x } \rho \text{ x } l$$

m = amount of putty in grams
r = fillet radius in mm
ρ = putty density in kg/l
l = fillet length in metres

Example:

A 14 metre long fillet with a radius of 40 mm shall be constructed with putty having a density of 1.68 kg /l.

$r^2 = 40 \text{ x } 40 = 1600$
$0{,}22r^2 = 352$
$352 \text{ x } 1{,}68 \text{ x } 14 = 8279{,}04 \text{ grams} \approx 8{,}3 \text{ kg}$

Necessary layer thickness

A floor covering's layer thickness is primarily determined by two factors:
a.   Grain maximum, i.e., the largest filler.
b.   Load size in relation to the substrate.

Normally, the general rule applies that states that the minimum layer thickness shall be three times the grain maximum.

Most epoxy coatings have very high compression strengths in comparison to concrete. Floor concrete usually has a compression strength of 25–35 MPa, while an epoxy coating has a compression strength of 70–100 MPa. By increasing the layer thickness, the load can be distributed over a larger area of concrete. The distribution area's size is shown in the figure below.

Example of use

A concrete floor of K30 concrete (compression strength 30 MPa) shall be used for truck traffic with a calculated load of 70 MPa. What is the least recommended layer thickness for a suitable epoxy coating?

To attain the distribution area, 70 is divided by 30, which is equal to 2.3. The distribution area should therefore be 2.3 times larger to withstand the heavier load. Find 2.3 on the vertical axis, go out to the curve, go straight down to the horizontal axis and read 2.6 mm.

A 3 mm epoxy coating is sufficient under the condition that the coating has a compression strength that exceeds 70 MPa.

Distribution surface, mm^2 / Layer thickness, mm
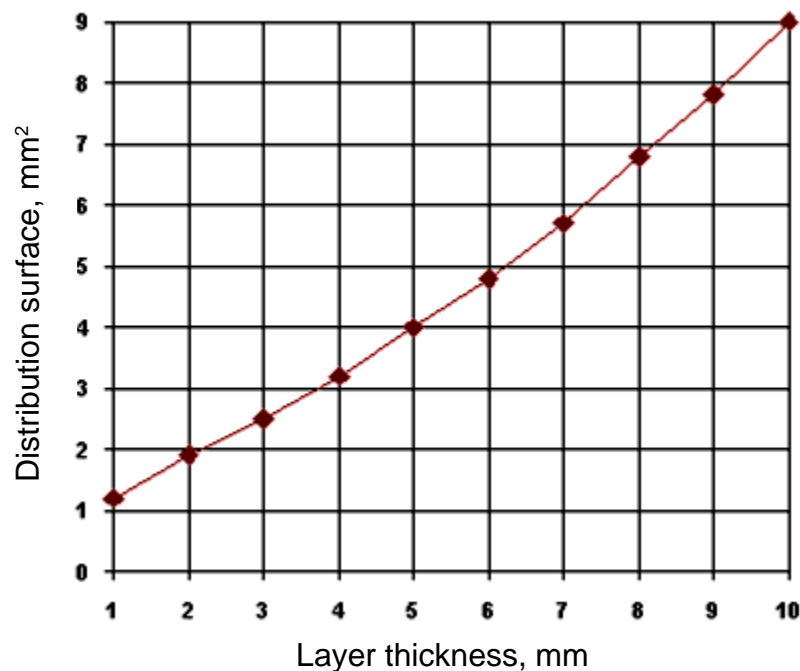
The requirements for surface treatments of concrete floors naturally vary within a wide range – everything from in principle, no treatment at all, to very sophisticated coatings with built-in flexible membranes, etc.

Despite the floor being among a structure's most important components, too little effort is perhaps expended on finding the best and proper covering. This often is because of lack of knowledge and placing all too much trust in the salesman's cheerful advertising brochures. One can never replace quality with long warrantees.

Fundamental for all surface coating systems is that they shall be designed to comply with specified requirements. Simply put, a floor covering consists of two basic elements, namely, the right product and the right execution. If one of these elements is faulty, the covering will also be faulty.

To be able to determine the right product, one must be sure of the requirements specified for the floor, and be knowledgeable of the various products' functions and properties. The requirements one shall place for the floor are attained through a so-called requirements analysis. Such an analysis can include:

- Mechanical stress on various parts of the floor
- Temperature variations
- Chemical stress
- Anti-skid
- Cleanability
- Freedom from pores
- Tightness
- Levelness
- Reparability

Mechanical stress

All floors are subjected to mechanical stress but this naturally varies within different parts of a building. To protect the concrete against high point loads, the coating must have a thickness that is determined by the load's size. Obviously, the coating material must have a compression strength that in itself withstands the load. Many product sheets entirely or partially lack information on mechanical strength.

Floors for truck traffic should never be thinner than 3 mm. For pedestrian traffic, it is often enough with 0.3 mm.

One of the most common reasons for coatings not lasting is that the purchaser chose a coating that was too thin. Practical experience has shown that one can expect load distribution with thicknesses from 3 mm. Extreme loads that arise from impact or from heavy objects being dropped or dragged along the floor can demand special arrangements such as fibreglass reinforcement. See the section "Necessary layer thickness" for more information.

Temperature variations

The floor's temperature while in use, as well as local temperature variations, is important to know when choosing products. All plastic-bonded coatings have a thermal expansion that is greater than that of concrete. In practice, this means that rapid variation in the floor temperature causes shearing stresses in the concrete-coating boundary layer. Such stress arises, for example, when warm water is spilled on the floor or in front of a bakery oven when the doors are opened. Of the binding agent types epoxy, polyurethane and methyl methacrylate (acrylic), epoxy has the lowest thermal expansion and withstands temperature variations well.

Under normal conditions, floors have a temperature of +15–20°C, and the coating material's properties are adapted to this temperature. If the normal temperature is higher, the coating's composition should be adapted to this.

Chemical stress

Chemicals that will come in contact with the floor coating should be known. In the machining industry, they are often cutting oils, hydraulic oils and solvents, but there are also a number of acids used in etching.

In the dairy branch, there is often lactic acid, and in the chemical industry, nearly anything can be found. The epoxy plastics have very good chemical resistance but there are naturally limits.

In studying chemical resistance lists, one shall be certain of how testing was carried out to be able to make relevant assessments. For example, it can be mentioned that an epoxy coating that is submerged in acetone breaks down relatively fast, but spills of acetone on a floor generally have no affect because the acetone is very volatile.

Anti-skid

Anti-skid, i.e. a certain roughness on the surface, is often on the wish list. In dry environments, it is usually unnecessary, but in wet environments and where spills of, for example, oils occur, it is necessary. The degree of anti-skid should be established by assessing a test coating, which will later be the norm in execution.

Cleanability

Cleanability is often related to the degree of anti-skid. Certain types of coatings have built-in anti-skid, which entails that quartz grains in the surface are encapsulated in a scratch-resistant lacquer layer. In this way, both cleanability and anti-skid are attained. Sometimes the requirements for cleanability are very stringent, for example, in nuclear power plants and laboratories. The coating shall then be completely smooth and glossy.

Freedom from pores

In the foodstuffs and pharmaceutical industries, there are naturally substantial demands for coatings being free from pores. Here, the orderer must be very observant. Certain types of coatings, primarily of the type dry mortars and toploaded screeds, can appear free from pores if one looks at the surface. If the coating shall be free from pores and tight, however, each quartz grain must be completely surrounded by binding agent. The supplier should be able to document tightness and freedom from pores. This can be accomplished with thin grinding or photography of a section in the coating.

Tightness

That tightness should be considered when planning is perhaps not entirely obvious. One often expects that an epoxy coating is tight, but so-called mortars of coloured sand and binding agent have, for reasons of application technique, too little binding agent. For these compounds, the binding agent content is normally about 15% by weight. Coloured quartz sand is relatively uniform, i.e. the grains are about the same size. For full saturation, binding agent of about 23% by weight is required. This difference cannot be compensated by surface lacquering. The low binding agent content is insufficient to wet the substrate, which is evident if the mortar is laid on a glass sheet. The tightness requirement sometimes demands that consideration be taken to cracking risks in the concrete substrate. Cracks that arise in the concrete after the coating is applied usually result in a crack in the coating. This is because an extension from 0 to something is always an infinitely large elongation, and no coating can withstand this. The only option is thus to first apply an elastic membrane of a few millimetres' thickness and thereafter a laminate of fibreglass and epoxy, followed by the ordinary coating.

Structure of crack bridging coating

One type of coating is sold just because of its fully open structure. It incorporates natural stone in sizes 4–6 mm that are held together by a very small amount of epoxy, normally 7–10% by weight.

This coating has an attractive appearance and is assumed to save on cleaning costs. This is correct because the open structure has space for quite a bit of dirt. A 15 mm thick coating has space for about 4 litres per square metre. The coating has become very popular, in among other areas, automobile showrooms. What one should not forget is that the open structure also has space for, for example, 4 litres of petrol per square metre, which can entail a very significant fire risk. One should also consider that the total surface area of stones in a 15 mm thick coating constitutes about 10 square metres of exposure per square metre of floor surface.

Levelness

A floor's levelness is often of fundamental importance. Examples are high bay storage areas and floors for hovercraft.

Minor unevenness in the substrate is evened out by coatings in thicknesses from a few millimetres and upwards, but large depressions must be levelled before coating. The most advantageous is if the levelling is accomplished with epoxy products instead of cement-stabilized compounds. This pertains to adhesion and surface strength.

Reparability

Damages that occur because of impact, chemicals or increased temperatures cannot be avoided. Such damages should be remedied as soon as possible to restore function. It can be generally said that epoxy coatings are easy to repair. However, one must expect that a small difference in shade or gloss will make the repair visible for a time.

If possible, the repair should be made with the same material as the coating. It is thus very important that coating work be documented, both by the orderer and the contractor.

When the requirements analysis is complete, it is time to find the products that can be expected to fulfil the set requirements.

Preferably, one should engage a reputable manufacture of epoxy products. If one chooses a supplier with a functioning quality system who is third-party certified, one is guaranteed that the products are well-controlled quality-wise prior to delivery, and that cans contain the right amounts of the right products. Additionally, each package from a quality certified manufacturer is labelled with a batch number, which makes the product traceable back to both final testing and testing for each included raw material. Analysis certificates for the supplier's products can always be obtained if so requested.

As mentioned in the introduction, a floor coating does not just consist of the right product, but also to a very high degree, the right execution. The installation of a coating is a craft and naturally places requirements on the contractor's skills, expertise and resources. The contractor must be able to assess the conditions for coating work, both in regards to the substrate's strength, cleanliness, temperature, etc., and the time it will take to correctly perform each of the various tasks. He should be able to place a quality plan at the orderer's disposal and be able to document all activities performed that can influence the quality of work executed.

Gluing

Glue refers to a material that is applied between two other materials in order to join them. The glue thus forms a joint that through its inner continuity (cohesion) and its adherence (adhesion) causes the joined material to form a unit.

There have been many theories as to how glue works, i.e. what adhesion actually is. Today, gluing capacity is considered a physical mechanism, namely adsorption (not to be confused with absorption, which means soaking up). Adsorption entails that molecules are drawn to one another by so-called **van der Waals** forces.

These forces are greatest when the distance between the molecules are of the size 3–4 angstrom (an angstrom [A] is equal to ten millionths of a millimetre). When the distance increases over 5 angstrom, the force is in principle infinite. In practice, this means that if it were possible to press together two surfaces so tightly that the distance was under 5 angstrom, a bond would occur. However, such smooth surfaces do not exist. A liquid, however, can form itself to the substrate and come sufficiently close. If the liquid can later be converted into solid form, without shrinkage, a glued joint occurs. A requirement for the liquid (the glue) coming sufficiently close is that it has a surface tension that is lower than the substrate's. The surface tensions for epoxy glues are in the range 35–45 mN/m.

Good weeting   No wetting
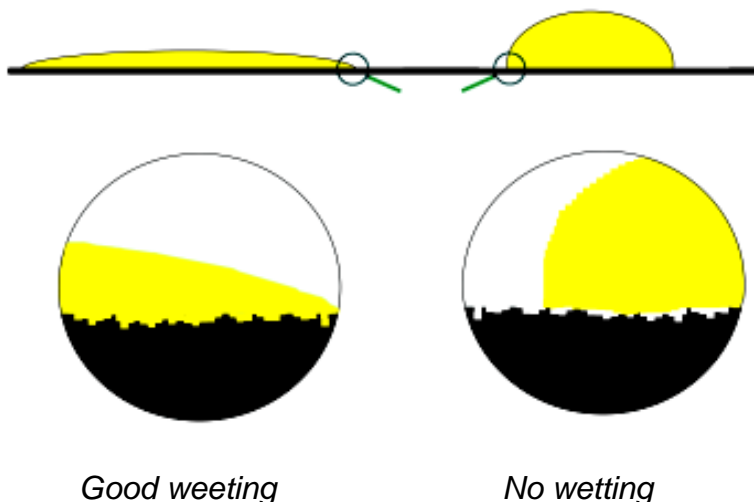
Materials that have lower surface tension than epoxy are difficult to glue. Examples of such materials are Teflon, with a surface tension of 18.5 mN/m, and polyethene, which is at 32 mN /m. Wood, however, with a surface tension of about 200 mN/m, and metals, which are between 200 and 2000 mN/m, are easily glued.

If the glue's surface tension is right, i.e. lower than the substrate's, one can say that the glue has the capacity to wet the substrate. This wetting capacity is also related to the glue's consistency.

The need to join together various things has existed since time immemorial. In nature, there are a number of gummy substances that have been used, but when it comes to strength, they naturally have their limitations.

Many other ways to join materials have been developed, for example, welding, soldering, riveting, bolted joints, etc. These methods also have many disadvantages. Welding and soldering are limited to joining metals, rivets and bolted joints are difficult to make tight; there is also always the risk for galvanic elements and corrosion. There is, and there has always been, a certain scepticism to glues. This is because previously, the common glue types did not have the right properties pertaining to strength, filling the joint, durability, etc. The situation today is entirely different. Glues have now been developed that comply with the requirements, and gluing techniques have been refined. Modern epoxy glues are presently replacing both welding and riveting in many cases.

To be able to choose the right glue for a joint, it is important to perform a requirements analysis.

Examples of requirement factors are:

- Which forces will affect the joint?
- Within which temperature ranges shall the joint function?
- Are the materials that will be joined absorbing?
- Do the materials require pre-treatment prior to gluing?
- Does the glue wet the material sufficiently?
- Is the joint such that it shall be filled?
- What are the hardening conditions?
- Shall the glue be mixed manually or with a machine?

A glued joint's capacity to transfer forces depends on how the forces shall be transferred. In principle, there are four basic cases, namely, tensile force, shearing force, tearing and splitting.

Epoxy glues have very high tensile strength and therefore withstand shearing forces well.

Resistance to tearing and splitting are, however, less favourable. It is thus important that joints be formed so that they are subjected to as little tearing and splitting as possible. Heat hardened epoxy glue of the single-component type generally has better resistance to tearing than room temperature hardened epoxy glue.

The joint's working temperature is also important to know. All glues have temperature limitations. In glue specifications, the glue's HDT (Heat Deflection Temperature) or Tg is often specified.

At HDT, the glue quickly loses strength. Room temperature hardened epoxy has an HDT of between + 40° and + 70°C. In exceptional cases, it is somewhat higher.

Heat hardened glues can withstand temperatures up to +250°C.

Splitting

Shearing

Tearing

Tensile
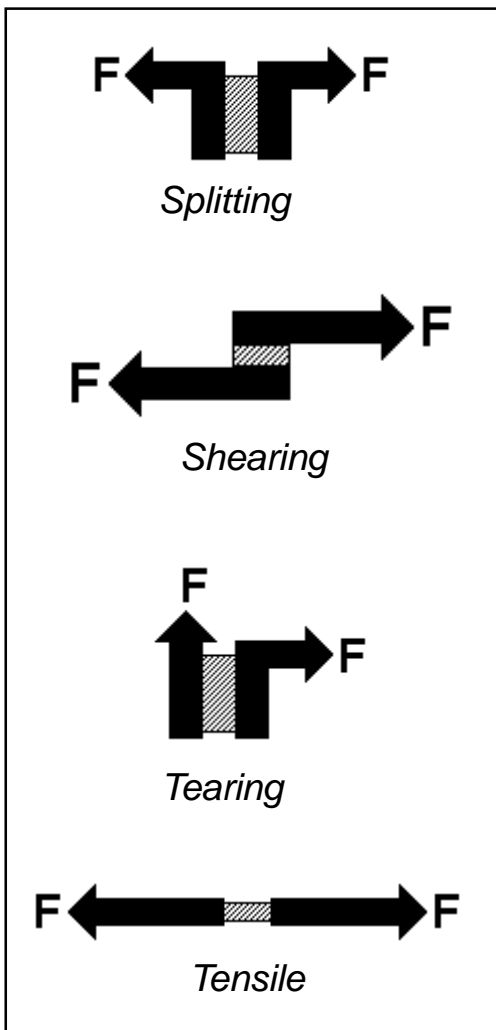
Various forces in glued joints

Furthermore, one should be aware of the differences in thermal expansion between the glue and the glued surfaces. If the difference is large, the glue must be able to withstand the stress that arises with temperature variations.

If the material that shall be glued is absorbent, i.e. can absorb a liquid, consideration must be taken to this when choosing glue.
Wood is an example of an absorbent material. A low viscosity glue with long open assembly time can entirely vanish into the wood, leaving the joint empty. The right type of filler can eliminate this risk. In some cases, it is necessary to saturate the wood with glue before actual gluing.

Very often, it is necessary to pre-treat the materials that will be glued. Examples of pre-treatments can be degreasing, sanding, sandblasting, etching, priming and blazing. At the end of this book, a number of suggestions are provided for pre-treatments that can be applicable.

Surface wetting is directly related to the pre-treatment that to a large extent consists of removing contaminants from the surface to be glued.
In addition to this, the glue's limitation is in its surface tension in relation to the substrate's surface tension.
When uneven surfaces are to be glued, the glue must be able to fill the gap that arises without the glue running out. An example is gluing of steel plate to concrete. Here the glue gap can be up to several millimetres.

The glue's consistency, or its rheology, is very important. When applying the glue, the consistency shall be such that the glue wets the surface. After application and attachment of the materials, the glue shall quickly build up a thixotropic consistency so as to not run out of the joint.

In regards to hardening conditions, it can be said that glue intended for room temperature hardening should be permitted to harden at +20°. At this temperature, it is easy to achieve reasonable hardening times, at the same time as one has a somewhat long potlife.
Epoxy can be made to harden down to temperatures of about ±0° C, but when it comes to glues, the limit should be set at about +10° C. All chemical reactions are

temperature dependent. For epoxy, what approximately applies is that an increase in temperature with 10° C doubles the reaction speed.

A post-hardening at increased temperature (+50–+100°C) is often required. It is namely so that at room temperature, polymerisation is nearly linear, i.e. with few cross linkings. At increased temperature, the reaction is complemented with several cross linkings and the end result is a stronger glue.

Heat hardened glue is often of the single-component type with long potlife at room temperature. These glues are normally hardened at temperatures between + 150°C and + 180°C. A hardening cycle with certain times at specified temperatures is often needed.

For continual gluing, mechanical equipment is often used to obtain well-mixed dosages of the components. It is important that such glues be developed in close collaboration with the glue manufacturer for final properties to be optimal.

In recent years, concrete has been clad or painted to an increasing degree. The reason for this, besides the aesthetic considerations, is to protect the concrete from aggressive media. Included as aggressive media are not just chemicals such as hydrochloric acid, sulphuric acid and certain salt solutions, but also gases, such as carbon dioxide, sulphur dioxide and nitrous oxides in aqueous solutions.

When concrete is of poorer quality, and/or the coverage is insufficient, these gases can mount serious attacks on the reinforcement and even completely destroy it under extreme conditions. Before discussing protection of concrete, it can be worthwhile to look at the chemical reactions that can occur under the influenced of CO_2, SO_2 and NO_X in combination with oxygen and water.

Composition of cement-stabilised construction material
Just as the name implies, all cement-stabilised materials contain cement as a binding agent. The cement, however, constitutes not only the glue, but also corrosive protection for the reinforcement. Cement consists primarily of calcium oxide and quartz, as well as small amounts of aluminium oxide, iron oxide, magnesium oxide, potassium oxide and sodium oxide. Common cement also contains small amounts of sulphates. Analysis data for Portland cement show approximately 63% calcium oxide (CaO), 1.2% potassium oxide (K_2O) and 0.15% sodium oxide (Na_2O).

Chemical reactions in the water-cement paste and in the hardened cement
It is of course a well-known fact that cement hardens (sets) through reactions between the various oxides and water.

As has been already mentioned, all cement contains potassium and sodium oxide. In most publications, these are also referred to, but very little has been devoted to these oxides significance in the chemical reactions in the water-cement paste.

There are publications that address the danger of excessively high contents of alkali oxides in the cement, but then in regards to the concrete structure's stability. These investigations mostly concern the reaction between alkali oxides and varying additives (for example, the silicon-alkali reaction in Denmark).

Experimental investigation
In a test, three core samples of concrete were used with varying strengths (K15, K35 and K55); the sample diameter was 9.5 cm. These were placed in beakers with a diameter of 10 cm and 400 cm^3 of distilled carbon dioxide-free water was poured over. The volume ratio was about 1:1. All of the concrete core samples consisted of the same cement and additive.

The three beakers were covered with watch glass, but not tightly. In this way, the surface was exposed to air. The air volume between the water surface and the watch glass was about 300 cm^3.

Each week, the contents of calcium, sodium and potassium were measured in the clear solution above the concrete. Additionally, the appearance and pH in the water were noted. Over an 8-week period, the contents of sodium and potassium rose in the water above the K35 and K55 samples, at the same time as the calcium content fell to nearly 0. In the water solution above sample K15, the calcium content rose somewhat more than the potassium and sodium contents. The pH value for K15 stopped at 12.5, while it rose to 13 for the K35 and K55 samples. In the K35 and K55 samples, a substantial precipitation of white, compact grained material formed; in sample K15, the precipitation was not as great. Closer examination showed that the precipitation consisted for the most part of calcium carbonate; a small amount was magnesium carbonate.

In research on the pore liquids in concrete, Heinz-Günter Smolczyk, Duisburg, has also established that with decreasing hydration time, the contents of Ca^{2+}, Cl^- and SO_4^{2-} decline, while Na^+ and OH^- ion concentrations increase.

Reaction mechanisms

When one observes the reactions of CaO, MgO, K_2O and Na_2O with water and CO_2 respectively, one discovers that with water, the hydroxides $Ca(OH)_2$, $Mg(OH)_2$, KOH and NaOH are formed. $Ca(OH)_2$ and $Mg(OH)_2$ are very difficult to dissolve in water. In the reaction with carbon dioxide, nearly insoluble products in the form of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are formed from the calcium and the magnesium hydroxides. Potassium and sodium hydroxide form very soluble carbonates. As can be seen in Table 1, water participates or is formed in all reactions, i.e. the reactions occur chiefly and accelerating in the liquid phase.

In Table 2, one can see that the sodium and potassium carbonates are not only very soluble, they also display a rather high pH value.

Furthermore, one sees that the potassium carbonate is about three times more soluble than sodium carbonate. In the reaction between potassium hydroxide or sodium hydroxide (strong base) and carbon acid (weak acid), potassium carbonate (sodium carbonate) and water are formed.

$$2\ KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$
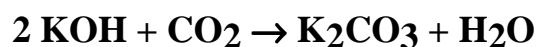
In the subsequent reaction between potassium carbonate (sodium carbonate) and calcium hydroxide, calcium carbonate and potassium hydroxide (sodium hydroxide) are formed.

$$K_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2\ KOH$$
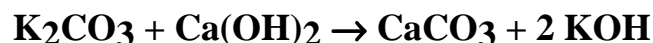
We can now see that the carbonating process of cement (concrete) goes via the sodium and potassium hydroxides. Both NaOH and KOH have a very high pH value even in weak concentrations. One-percent solutions have a pH value of about 13. Because of what has been said previously, it is hardly meaningful to look to the carbonating front with phenolphthalein, because the phenolphthalein's colour shifts at pH 9. This has also been seen in comparison between phenolphthalein and complete analysis.

*The carbonating front is often 3 times deeper that what the phenolphthalein shows.*

Influence of sulphur oxide and nitrous oxides on concrete

The content of sulphur dioxide (SO_2) in air is usually between 0.1 and 0.2 mg/m^3 air in industrial atmospheres.

The nitrous oxide in heavily trafficked environments can reach values of about 1.4 mg/m^3 air. Nitrous oxides are most often denoted as NO_X, which encompasses both nitrogen monoxide (NO) and nitrous oxide (NO_2).

The reaction formulas in Table 3 show that the sodium and potassium salts are very soluble in water. Magnesium sulphate is somewhat soluble; all nitrates are very soluble. None of the salts shows alkalinity, but rather the opposite, weak acid reaction.

In the action of nitrous oxide on cement in the presence of oxygen, the following reaction occurs:

$$2\ KOH + 2\ NO_2\text{-}O_2 \rightarrow 2\ KNO_3$$
$$2\ KNO_3 + Ca(OH)_2 \rightarrow Ca(NO_3)_2 + 2\ KOH$$
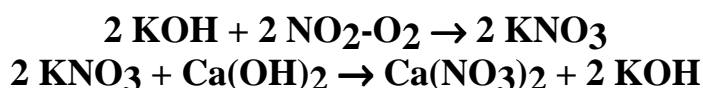
If carbon dioxide is also present, the neutralisation of the concrete is substantially quickened.

$$2\ KOH + CO_2 \rightarrow K_2CO_3$$
$$K_2CO_3 + Ca(NO_3)_2 \rightarrow CaCO_3 + 2\ KNO_3$$
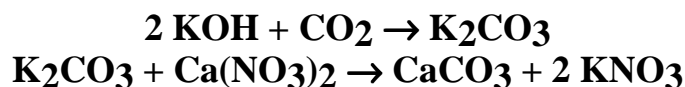
Effects of corrosion on reinforcement bars

It is established that steel corrodes in the presence of sulphate ions, even in alkalic solutions. With atmospheric corrosion of steel, it is known that the presence of sulphates quickens corrosion with a factor of 10^3 to 10^4. It reacts the same with nitrates.

In testing, steel plates, which were sandblasted, primered and painted with two coats of epoxy, were submerged in solutions of sodium chloride, magnesium chloride solution with magnesium sulphate and sodium chloride, cement slurry and cement slurry with an additive of 3% sodium nitrate. After several weeks of storage, the test object in nitrate/cement slurry was so strongly corroded that the entire coating was underfilm corroded and detached; the pH value was about 12 during the entire period. Other plates demonstrated, in principle, no damages at all, with the exception of minor amounts at the cut edges.

Conclusion

Binding agents in concrete contain hydroxides of calcium, magnesium, sodium and potassium. Water solutions of sodium and potassium hydroxide show a pH of 12–13.5, even in low concentrations. The chemical process is determined by the reactivity and aggregation state (solid or in solution). The concrete's reaction to carbon dioxide, sulphur dioxide and nitric oxides therefore occurs to a very small degree via the difficult to dissolve calcium hydroxide, but to a very large degree with the easily soluble and reactive sodium and potassium hydroxides. Carbon dioxide in air reacts first with sodium hydroxide, respectively, potassium hydroxide, first thereafter in accordance with the chemical laws, such as anion with the calcium cation. The created sodium and potassium cations react with the hydroxide anion and the easily dissolved initial hydroxides reform. In accordance with what has been previously pre-

sented and that which is also indicated in the literature (Smolczyk), it is thus incorrect to consider the pore liquids in the cement concrete as primarily saturated calcium hydroxide solution. The alkalinity in the pore liquids is determined almost exclusively by the sodium and potassium carbonate and sodium and potassium hydroxide.

After completed carbonation, i.e. when the calcium, sodium and potassium hydroxides are transferred to respective carbonates, to a much larger degree, the soluble sodium and potassium carbonates (with pH values between 12 and 13) account for the chemical reactions with sulphur and nitric oxides, respectively. Sodium and potassium carbonate are transferred to sulphates and nitrates, respectively, followed by the reaction with calcium hydroxide.

When one attempts to establish the carbonation depth with phenolphthalein solution, one is under the impression that one indicates calcium hydroxide with a colour shift to red. Actually, it is sodium and potassium carbonate, and/or sodium and potassium hydroxide that causes the colour shift, while calcium can exist as carbonate.
The phenolphthalein method does not indicate anything at all in regards to the carbonation state of concrete, and in particular, nothing of various calcium compounds. One does often attain uncoloured zones in the phenolphthalein test, and chemically, two states can then exist.

A) The easily soluble sodium and potassium carbonates and hydroxides are washed out after complete carbonation of the calcium compounds. This case can only occur when no soluble carbonates or hydroxides, from deeper layers, can reach the surface. This can be the case if an ion concentration arises under blocked pores, for example, if a surface is infused with much water.

B) The calcium hydroxide is completely carbonated. The soluble carbonates and hydroxides (Na and K) have later reacted with sulphur and nitric oxide, respectively, and formed neutral salts.

Covering of concrete and other cement-stabilised materials
In constructions that are often subjected to normal outdoor environments, reinforcement bars are most often sufficiently protected if the covering is sufficient and if the concrete quality is good enough. If this is not the case, or if the construction is often soaked by rain in combination with air pollutants, corrosion damages can occur.
Such constructions should be protected with a covering that protects against water, carbon dioxide, nitric oxides, sulphur dioxide and acid.
With today's technology, it is primarily unsaponifiable materials based on epoxy, polyurethane or acrylate that are possible options. When it comes to visible constructions, the material must also be sufficiently weather resistant. In investigations of damages that have occurred to coverings, it is usually the case that the material has not been sufficiently saponifiable resistant. It has been shown several times that additives of saponifiable softening agent damage otherwise impervious materials.

In analysis of the content of blisters on coatings, it has been shown that they primarily contain potassium salts, and to a certain extend, sodium salts. Calcium salts almost never occur. This means that the coating material must be resistant to potassium and sodium hydroxide solution.

Table 1

Chemical sub-reactions in cement and concrete in the presence of water and carbon dioxide.

	B	A
CaO + H_2O $\longrightarrow$ Calcium oxide	$Ca(OH)_2$ + CO_2 $\longrightarrow$ *Calcium hydroxide*	$CaCO_3$ + H_2O *Calcium carbonate*
	B	A
MgO + H_2O $\longrightarrow$ *Magnesium oxide*	$Mg(OH)2$ + CO_2 $\longrightarrow$ *Magnesium hydroxide*	$MgCO_3$ + H_2O *Magnesium carbonate*
	D	D
K_2O + H_2O $\longrightarrow$ *Potassium oxide*	$2\ KOH$ + CO_2 $\longrightarrow$ *Potassium hydroxide*	K_2CO_3 + H_2O *Potassium carbonate*
	D	C
Na_2O + H_2O $\longrightarrow$ *Sodium oxide*	$2\ NaOH$ + CO_2 $\longrightarrow$ *Sodium hydroxide*	Na_2CO_3 + H_2O *Sodium carbonate*

A. Nearly insoluble　　　　　　　　　　B. Sparingly soluble
C. Partially soluble　　　　　　　　　　D. Soluble

Table 2

The pH value of some compounds in cement-stabilised material and concrete, and their solubility.

Chemical compound Formula	pH value at 20°C and associated concentrations		Solubility in distilled water (20°C) grams/100 ml
	pH	Weight%	
Calcium hydroxide $Ca(OH)_2$	12.6	0.2 saturated solution	app. 0.2
Magnesium hydroxide $Mg(OH)_2$	app.10	< 0,1	< 0.001
Potassium hydroxide KOH	13.2 14.1	1 10	app.250
Sodium hydroxide NaOH	13.4 14.3	1 10	app. 150
Potassium carbonate K_2CO_3	11.6 12.5	1 20	app. 120
Sodium carbonate Na_2CO_3	11.5 12.2	1 20	app. 40

Table 3

Chemical sub-reactions in cement and concrete in the presence of water (H_2O), oxygen(O_2), sulphur dioxide (SO_2) and nitrous oxide (NO_X).

Reactions in cement	Reactions in concrete	Reaction products
$CaO + H_2O$ *Calcium oxide* $CaO + H_2O$	$\longrightarrow Ca(OH)_2 + SO_2$ *Calcium hydroxide* **[2]** $\longrightarrow Ca(OH)_2 + NO_X$	$\longrightarrow CaSO_4 + H_2O$ *Calcium sulphate* **[2]** $\longrightarrow CaNO_3 + H_2O$ *Calcium nitrate* **[4]**
$MgO + H_2O$ *Magnesium oxide* $MgO + H_2O$	$\longrightarrow Mg(OH)_2 + SO_2$ *Magnesium hydroxide* **[2]** $\longrightarrow Mg(OH)_2 + NO_X$	$\longrightarrow MgSO_4 + H_2O$ *Magnesium sulphate* **[3]** $\longrightarrow Mg(NO_3)_2 + H_2O$ *Magnesium nitrate* **[4]**
$K_2O + H_2O$ *Potassium oxide* $K_2O + H_2O$	$\longrightarrow 2\ KOH + SO_2$ *Potassium hydroxide* **[4]** $\longrightarrow 2\ KOH + NO_X$	$\longrightarrow K_2SO_4 + H_2O$ *Potassium sulphate* **[4]** $\longrightarrow 2\ KNO_3 + H_2O$ *Potassium nitrate* **[4]**
$Na_2O + H_2O$ *Sodium oxide* $Na_2O + H_2O$	$\longrightarrow 2\ NaOH + SO_2$ *Sodium hydroxide* **[4]** $\longrightarrow 2\ NaOH + NO_X$	$\longrightarrow Na_2SO_4 + H_2O$ *Sodium sulphate* **[4]** $\longrightarrow 2\ NaNO_3 + H_2O$ *Sodium nitrate* **[4]**

[1] = Nearly insoluble   [2] = Sparingly soluble
[3] = Partially soluble   [4] = Soluble

Recommendations for those who handle epoxy resins and hardeners

There are currently about 2 million chemical compounds. Many of these we use daily without considering them as chemicals, for example, soap, salt, perfume, alcohol, tobacco, etc. These products, that we constantly use, normally cause no ill effects to our health. The reason for this is that over a long period, we have learned to use them in a risk-free manner.

It is of the greatest importance that we learn to understand how the chemicals we use affect our bodies.

The epoxy resins and their hardeners are complex chemical compounds that in certain cases can give rise to injuries if they are handled in an incorrect manner.

Since the 1950s, the epoxy resins have been used in industry and painting. This is a relatively long time, which gives us certain experience of these plastics' properties. The recommendations that we provide here can to some extent generally apply for all handling of epoxy resins and hardeners. We would like to point out, however, that the recommendations apply to products manufactured by Nils Malmgren AB. In cases where local labour safety regulations exist, these shall always be observed.

Which risks for injuries are there in handling of epoxy resins and hardeners?

One can expose oneself in three ways: through the mouth (orally), through skin contact (dermally) and through breathing (inhalation) of vapours or dust.

The pure epoxy resins are considered as non-toxic while most hardeners have a certain amount of toxicity. The risk for injuries caused by the oral intake of epoxy resin, however, may be considered as very slight.

The problems that are caused by epoxy resin and hardener most often arise through skin contact. It can be in the form of irritation and sensitising. On the skin, irritation can cause toxic eczema and sensitising allergic contact eczema.

Among the hardeners, the aliphatic polyamines cause the most skin injuries. They are strongly alkalic and can cause irritations and caustic injuries. Injuries caused by amines can prepare the skin for epoxy eczema.

Amine adducts and polyamides are generally less irritating to the skin than the pure amines. The pure amines are to a certain extents sensitising, while adducts and polyamides hardly ever lead to allergic contact eczema. Inhalation of epoxy resins causes no problems because they are not volatile. As a rule, the hardeners have a stinging odour that can cause temporary irritation in the air passages. Inhalation of amines does not normally cause toxic reactions.

Epoxy resins used in Nils Malmgren AB's products are not carcinogenic according to the literature that exists on the subject. However, aromatic amines such as 4.4-diaminodiphenylmethane are classified as carcinogenic, and may only be handled subject to approval by local labour safety regulations.

How are epoxy products handled to avoid injuries?

As stated previously, it is primarily skin contact that shall be avoided. To prevent skin contact, one must always be aware of how the epoxy products shall be handled.

Hygiene at the workplace

Extreme cleanliness at the workplace is of the greatest importance. To make this easier, products from Nils Malmgren AB are manufactured and packaged ready for use. One of the cans in a kit generally contains both the components and mixing measure.

Ventilation at the workplace shall be as good as possible. Use special tools for epoxy work, keep them clean and do not lend them to those who do not work with epoxy.

Do not let empty cans stand without lids; dispose of them immediately in the specified container. Any spilled material is wiped up immediately before it spreads.

Do not touch door handles, faucets and similar objects with contaminated work gloves.

Work clothing

Hands, wrists, face and eyes are the most exposed. These parts of the body must be protected from contact with epoxy materials.

There is naturally a theoretic possibility to protect the entire body from contact with everything by wearing sealed plastic clothing, plastic gloves, hood, rubber boots and the like, but the risk is substantial that one would thus create other types of irritations, for example, through perspiring and difficulty of movement. The choice of suitable work clothing must therefore be judicious. To protect the torso, legs and arms, overalls are suitable articles of clothing. The legs and arms, however, must be sufficiently long, i.e. that they are long enough to cover the wrists and ankles. Overalls of the disposable type can be good for short periods of work that are hazardous from the contamination standpoint.

Gloves are available in many types and qualities. All disposable gloves are of plastic and can seldom be used continually for a longer period. It is practical to use thin 100% cotton gloves under plastic gloves.

Where there is a risk for splashing, for example, in the mixing of low-viscosity material, face guards or safety goggles should be used.

When sanding hardened epoxy plastic, carbon filter masks and dust filters of class P3 shall be used, and to a large extent, in combination with extraction.

As footwear, besides boots and high-top leather shoes, wooden clogs are also useful. The main thing is that the heel is sufficiently high that the overalls protect the ankles and heels without dragging on the floor.

It is important that contaminated work clothing is immediately changed, and contaminate and broken gloves discarded. If plastic gloves of the non-disposable type are used, these shall be cleaned on the outside before removal.

Personal hygiene

Personal hygiene is a well-documented factor when it comes to continuous handling of chemicals. Hands shall be carefully washed before meals, visits to the WC and smoking. Use soap and water or hand cleaning cream.

Solvents may never be used for cleaning hands.

Keep fingernails short and clean. Do not wear rings or wristwatches while working.

Do not eat and smoke in the work area.

Do not wear work clothing in eating areas.

Use a skin cream on the hands after washing to prevent drying and cracking.

Healthy and pliant skin reduces the risk for irritations.

Transport and storage

Epoxy resins and hardeners shall be transported and stored in sealed original packaging to avoid contamination of transport vehicles and storage areas.

Hardener labelled with the so-called corrosion symbol shall be package in such a way that the requirements for the transport of hazardous goods (ADR) are complied with.

When storing, the materials shall be placed on plastic film, preferably at the location where mixing is performed. Plastic film prevents any spills from being absorbed by the substrate, for example, concrete. In the event of material spills, sawdust, wood shavings, paper, cleaning rags and similar disposable products for cleaning are recommended. Discard the removed material in trash containers for epoxy waste. Clean dustpans and the like immediately with solvent.

Measures in the event of accidents

In the event of splash in eyes, flush in running water for at least 15 minutes. At workplaces that lack running water, use eye rinse, which shall always be on hand. Seek medical care immediately, say if the material can be strongly alkalic from hardener, take product information with you.

In the event of skin injury, wash in cold water, apply a dry bandage and seek medical care.

In the event of nausea, go out into the fresh air. If the symptoms do not disappear, seek medical care.

Ames Test

To be able to know as much as possible about our products, we have performed testing according to the Ames Test for ten of our most common products, but the selection is such that all used raw materials are represented.
None of the tested products in this test indicated any mutagenic or toxic effects.

The Ames Test is an indirect method for indicating carcinogenic substances.
There is presently no test that with 100% certainty can prove if a substance causes or does not cause cancer in humans. Animal testing with a large number of laboratory animals is considered the most reliable system for proving a substance's carcinogenic effects. These tests are, however, very costly and require extensive amounts of time to perform.
Several indirect methods have been developed for showing substances' carcinogenic effects. One of these is the Ames Test, in which a substances' mutagenic effects are shown using especially "designed" strains of bacteria.
There is a statistic connection between mutagenic effect and the capacity to cause cancer. Therefore, the substances that can cause mutations (hereditary changes in sets of genes) should be considered as potential cancer-causing substances. Ames has shown that there is an approximately 90% correlation between mutagenic effect and carcinogenic capacity. Correlation nearly as good is shown between the lack of mutagenic and carcinogenic effects.

Interpretation of results from Ames Test
If a substance is shown to be negative in the Ames Test, one cannot classify it as "non-carcinogenic" because one does not know exactly how cancer occurs. In the same way, one cannot with absolute certainty say that a substance with positive results in the Ames Test is carcinogenic for humans.
Positive results shall be interpreted as an indication that the substance can cause cancer in humans.
Therefore, the Ames Test shall be seen as a screening test, which at an early stage can indicate substances with a potential carcinogenic effect. To achieve further reliability, the substance should be further examined in laboratory animal testing.

Notes

Suggestions for pre-treatment of various materials

Metals

Aluminium and aluminium alloys

1. Degrease and submerge the object in the following solution:

       66 parts by weight, sodium dichromate
     666 parts by weight, concentrated sulphuric acid (H_2SO_4)
    1000 parts by weight, water

    The solution should have a temperature of 40–60°C, treatment time 5-20 minutes. After treatment, the objects shall be rinsed under running water, dried in air and glued or coated within 5 hours.

2. Steam degreasing/sandblasting, grinding
   Degreasing shall always precede sandblasting or grinding. Dust and loose particles are washed away with water or with solvent after sandblasting. Gluing or coating shall be performed within 30 minutes.

Beryllium

Degrease and submerge the object for 3 minutes in 80°C 20% sodium hydroxide solution (NaOH).

Lead

Degreasing and grinding.

Gold

Degreasing

Iron and steel

For iron objects, degreasing and sandblasting is sufficient for good adhesion. It is very important, however, that gluing or coating is performed directly after sandblasting.

Stainless steel

Stainless steel is among the most difficult materials to adhere to.
The following bath is used:

50	parts by weight, concentrated hydrochloric acid (HCl)
2	parts by weight, 30% hydrogen peroxide (H_2O_2)
10	parts by weight, 37% formaldehyde solution (HCOH)
45	parts by weight, water

The object is submerged for 10 minutes at a temperature of 65°C.

Cadmium

Electroplating with silver.

Copper and copper alloys

Etch at room temperature with the following bath:

15	parts by weight, 42% iron (III) chloride solution
30	parts by weight, concentrated nitric acid (HNO_3)
197	parts by volume, water

Chromium

Etch for 1 to 5 minutes at 90°C in the following solution:

8.5	parts by weight, concentrated hydrochloric acid (HCl)
10	parts by weight, water

Magnesium and magnesium alloys

Degrease and etch for 3 minutes at room temperature with the following solution:

83	parts by weight, chromium (VI) oxide (CrO_3)
100	parts by weight, sodium nitrate ($NaNO_3$)
400	parts by weight, concentrated acetic acid (CH_3COOH)
400	parts by weight, water

Nickel

Etch for 5 seconds in concentrated nitric acid (HNO_3)

Silver

Degrease and sand with fine emery cloth.

Tin

Degrease and sand with emery cloth.

Titanium alloys
Treat for 5 minutes with the following solution:

  10   parts by weight, sodium fluoride
   5   parts by weight, chromium (VI) oxide (CrO_3)
  50   parts by weight, sulphuric acid (H_2SO_4)
 250   parts by weight, water

Zinc and zinc alloys
1. Degrease and sand with emery cloth.
2. Etch with the following solution for 2–4 minutes at room temperature:

  20   parts by weight concentrated hydrochloric acid (HCl)
  80   parts by weight, water

Plastics
Most hard plastics, such as epoxy, phenol plastics, polyesters and polyurethane can after degreasing with most solvents (e.g. acetone) and sanding, be glued or coated. For thermal plastics, however, the right pre-treatment must be determined.

Aromatic polyamide
Grinding or sandblasting.

Linear polyamide
Wet surface for about 10 minutes with a 15% solution of phenol in water.

Linear polyester
1. Hardening at temperature over 135°C generally provides good adhesion.
2. 10 seconds in a 2% solution of vinyl trichlorosilane in xylene

Polyethylene and polypropylene
Etch with the following solution for 2 minutes:

 200   parts by weight, concentrated sulphuric acid (H_2SO_4)
  16   parts by weight, potassium dichromate ($K_2Cr_2O_7$)
  50   parts by weight, water

Polystyrene
Flame the surface with oxidizing flame.

Polyvinylchloride
Hard PVC can be sanded or sandblasted.
Softened PVC can be primed with polyurethane primer as sealing against softener migration.

Miscellaneous
Concrete
1. Sanding or sandblasting.
2. Etching with 10% hydrochloric acid (HCl)

Glass
Degreasing

Rubber
Treat the surface with concentrated sulphuric acid (H_2SO_4)

Leather
Degreasing and buffing.

Porcelain
Degrease and sand with emery cloth.

Wood
Sanding.

Precious stones
Degreasing.

Conversion table

Moment of force

1 kpm	9,807	Nm		0,1020	kpm
1 lbf · in	0,1130	Nm		8,851	lbf·in
1 lbf · ft	1,356	Nm	1 Nm =	0,7376	lbf·ft
1 ton · ft UK	3037	Nm		$0,3293 \cdot 10^{-3}$	ton·ft UK
1 ton · ft USA	2711	Nm		$0,3688 \cdot 10^{-3}$	ton·ft USA

Pressure, mechanical tension

1 bar	$100 \cdot 10^3$	Pa		$10 \cdot 10^{-6}$	bar
$1 \ kp/cm^2 = at$	$98,07 \cdot 10^3$	Pa		$10,2 \cdot 10^{-6}$	$kp/cm^2 = at$
$1 \ kp/mm^2$	$9,807 \cdot 10^6$	Pa		$0,102 \cdot 10^{-6}$	kp/mm^2
1 torr	133,3	Pa		$7,501 \cdot 10^{-3}$	torr
1 atm	$101,3 \cdot 10^3$	Pa	1 Pa =	$9,869 \cdot 10^{-6}$	atm
$1 \ lbf/in^2$	$6,895 \cdot 10^3$	Pa		$0,1450 \cdot 10^{-6}$	lbf/in^2
$1 \ ton/in^2 \ UK$	$15,44 \cdot 10^6$	Pa		$64,6 \cdot 10^{-9}$	$ton/in^2 \ UK$
$1 \ ton/in^2 \ USA$	$13,78 \cdot 10^6$	Pa		$72,3 \cdot 10^{-9}$	$ton/in^2 \ USA$

Density

$1 \ g/cm^3 = kg/dm^3$	10^3	kg/m^3		10^{-3}	$g/cm^3 = kg/dm^3$
$1 \ Ib/in^3$	$27,68 \cdot 10^3$	kg/m^3	$1 \ kg/m^3 =$	$36,13 \cdot 10^{-6}$	Ib/in^3
$1 \ Ib/ft^3$	16,02	kg/m^3		$62,43 \cdot 10^{-3}$	Ib/ft^3
$1 \ Ib/yd^3$	0,5933	kg/m^3		1,686	Ib/yd^3

Length

1 in	$25,4 \cdot 10^{-3}$	m		39,37	in
1 ft	0,3048	m		3,281	ft
1 yd	0,9144	m	1 m =	1,094	yd
1 mile	$1,609 \cdot 10^3$	m		$0,6214 \cdot 10^{-3}$	mile
1 nautical mile	$1,852 \cdot 10^3$	m		$0,5400 \cdot 10^{-3}$	nautical mile

1 angstrom = 10^{-10} m   1 Swedish mile = 10^4 m = 10 km

Area

$1 \ in^2$	$20,6452 \cdot 10^{-3} \ m^2$			$1,550 \cdot 10^3$	in^2
$1 \ ft^2$	$92,90 \cdot 10^{-3} \ m^2$			10,76	ft^2
$1 \ yd^2$	$0,8361$	m^2	$1 \ m^2 =$	1,196	yd^2
1 acre	$4,047 \cdot 10^3 \ m^2$			$0,2471 \cdot 10^{-3}$	acre
$1 \ mile^2$	$2,590 \cdot 10^6 \ m^2$			$0,3861 \cdot 10^{-6}$	$mile^2$

1 a (are) = $100 \ m^2$ 1 ha (hectare) = 100a   1 acre = $4936 \ m^2$

Volume

$1 \ in^3$	$16,39 \cdot 10^{-6} \ m^3$			$61,02 \cdot 10^3$	in^3
$1 \ ft^3$	$28,32 \cdot 10^{-3} \ m^3$			35,31	ft^3
$1 \ yd^3$	0,7646	m^3	$1 \ m^3 =$	1,308	yd^3
1 gallon UK	$4,546 \cdot 10^{-3} \ m^3$			220,0	gallon UK
1 gallon USA	$3,785 \cdot 10^{-3} \ m^3$			264,2	gallon USA

Force

1 dyn	$10 \cdot 10^{-6}$	N			$0,1 \cdot 10^{-6}$	dyn
1 kp	9,807	N	1 N =		0,1020	kp
1 lbf	4,448	N			0,2248	lbf

The unit kilo pound (kp) has also been referred to as kilogram force (kgf)

Mass

1 lb	0,4536	kg			2,205	lb
1 slug	14,594	kg			$68,52 \cdot 10^{-3}$	slug
1 oz	$28,35 \cdot 10^{-3}$	kg			35,27	oz
1 cwt	50,80	kg	1 kg =		$19,68 \cdot 10^{-3}$	cwt
1 ton UK	$1,016 \cdot 10^{3}$	kg			$0,9842 \cdot 10^{-3}$	ton UK
1 sh cwt USA	45,36	kg			$22,05 \cdot 10^{-3}$	sh cwt USA
1 sh tn USA	907,2	kg			$1,102 \cdot 10^{-3}$	sh tn USA

The seven basic units:

Length	1 m	metre
Mass	1 kg	kilo
Time	1 s	second
Electrical current	1 A	ampere
Temperature	1 K	kelvin
Luminance	1 cd	candela
Amount of substance	1 mol	mol

Two supplemental units

Flat angle	1 rad	radian
Solid angle	1 sr	steradian

Fifteen derived units with unit names

Frequency	1 Hz	hertz	$= 1 / s$
Force	1 N	newton	$= 1 \text{ kg} \cdot m/s^2$
Pressure, mechanical tension	1 Pa	pascal	$= 1 \text{ N}/m^2$
Energy, work	1 J	joule	$= 1 \text{ N} \cdot m$
Power	1 W	watt	$= 1 \text{ J} / s$
Electrical charge	1 C	coulomb	$= 1 \text{ A} \cdot s$
Electrical potential (electrical voltage)	1 V	volt	$= 1 \text{ W} / A$
Capacitance	1 F	farad	$= 1 \text{ C} / V$
Resistance	1 Ω	ohm	$= 1 \text{ V} / A$
Conductance	1 S	siemens	$= 1 \text{ A} / V$
Magnetic flux	1 Wb	weber	$= 1 \text{ V} \cdot s$
Magnetic flux density	1 T	tesla	$= 1 \text{ Wb} / m^2$
Induktance	1 H	henry	$= 1 \text{ Wb} / A$
Luminous flux	1 lm	lumen	$= 1 \text{ cd} \cdot sr$
Illumination	1 lx	lux	$= 1 \text{ lm} / m^2$

Multipel prefixes		
10^{12}	**T**	= tera
10^{9}	**G**	= giga
10^{6}	**M**	= mega
10^{3}	**k**	= kilo
10^{2}	**h**	= hecto
10	**da**	= deca
10^{-1}	**d**	= deci
10^{-2}	**c**	= centi
10^{-3}	**m**	= milli
10^{-6}	**μ**	= micro
10^{-9}	**n**	= nano
10^{-12}	**p**	= pico
10^{-15}	**f**	= femto
10^{-18}	**a**	= atto

Notes

Notes

Index

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