Understanding and preventing corrosion

KAIMANN

Understanding and preventing corrosion

**Part 1: What is corrosion
and how does it occur?**

**Part 2: Corrosion, protection and insulation:
it all depends on the right combinations**

Anyone who works with insulation products has to take note of many things that don't necessarily belong to their core business and/or they didn't learn during their training. Due to the potential damage it can cause and the consequential damage and loss, corrosion is one of the most important of these. If you know what corrosion is and how it occurs, you can also take preventative measures to avoid the feared CUI – corrosion under insulation. This fact sheet of technical information is intended to provide you with a comprehensible introduction to the topic. The first part discusses corrosion itself, its forms and characteristics. The second part looks at potential protection and prevention strategies and the interaction between insulation and installation.

1.   What triggers corrosion?

Rust is not corrosion. Rust is a result of corrosion. When rust appears on a ferrous surface, it was actually a long time prior to that that a chemical process began changing the metal. All metals and their alloys – however different they may be – essentially have the same structure. Metals consist of innumerable atoms that can be imagined as balls and that are arranged in a very regular pattern (a so-called "metal matrix"). These balls have a "hard" core that has a positive charge, and a "soft" shell that has a negative charge, or rather: a positively charged nucleus and a negatively charged electron shell (Fig. 1).
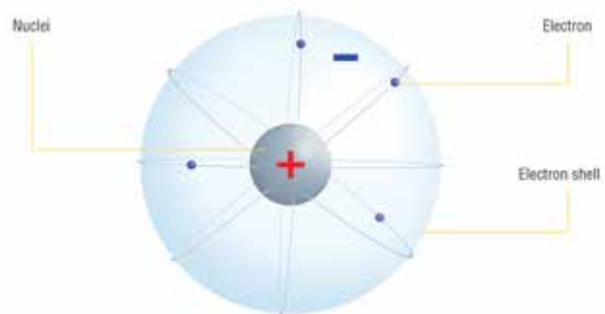
The electrons that form this shell can be imagined as minuscule balls circling around the core like planets around the sun – albeit at the speed of light. The positive and negative charges keep each other in equilibrium and the electrons thus remain within the shell. If we now connect several metal atoms to one another, i.e. stack the balls in a regular manner next to or above one another, something strange happens. The electrons no longer remain on their orbital paths, but move around freely in the spaces between the nuclei. They become so "blurred" that they are referred to as electron gas. They can no longer be associated with individual nuclei, only the entire atomic mass. Within a metal, the electron gas is therefore the negatively charged "binding agent" that holds the positively charged nuclei together. If the binding agent or the binding agent-core equilibrium is disturbed, the metal composite is weakened. This is how corrosion starts.

2. Types of corrosion

DIN EN ISO 8044 identifies 36 (!) types of corrosion. To simplify matters, we shall divide them into two categories: Classic corrosion (usually oxygen or hydrogen corrosion: manifests itself as contact corrosion, uniform corrosion, shallow pit corrosion, crevice corrosion or pitting corrosion) is more widely known and more common; corrosion cracking is less common, but insidious. Both begin undetected on the atomic level but develop differently. The standard provides the following definition: "Corrosion is understood to be the reaction of a met¬al with its surroundings, which brings about a measurable change to the materi¬al and can affect the function of a mechanical component or an entire system. This reaction is usually of an electrochemical nature, but sometimes it can also be of a chemical or metal-physical nature."

2.1 Classic corrosion

2.1.1 Basis: the chemical element

It is known that corrosion or the formation of rust involves water, or at least moisture. It is also known that the combination of metals of different "nobility" can also be critical. This already sets out the prerequisites for classic corrosion:

- you need a base metal (the anode or negative pole),
- a slightly more noble metal (the cathode or positive pole) in direct contact (contact corrosion) or (at least intermittently) with some sort of electrically conductive connection,
- along with an aqueous and thus likewise electrically conductive connection between the two (the electrolyte).

This combination creates an "electro-chemical element" (also known as a galvanic element), i.e. a structure through which electrical currents can flow by electrons migrating from the anode to the cathode. The anode – the base metal – thus loses electrons, which causes its electron gas to thin and the anode to lose some of its internal cohesion. Metal atoms on the surface of the metal change into ions (with a

positive charge as due to the lack of electrons the positive charge of the nucleus now prevails) and work loose, form salts, lead to peeling, etc.

It is very easy to demonstrate such processes by placing a (base metal) zinc plate in contact with a (noble metal) steel plate in a saline solution (Fig. 2); normally, steel would rust quickly in such an aggressive environment, but the zinc breaks down whilst the steel remains shiny.
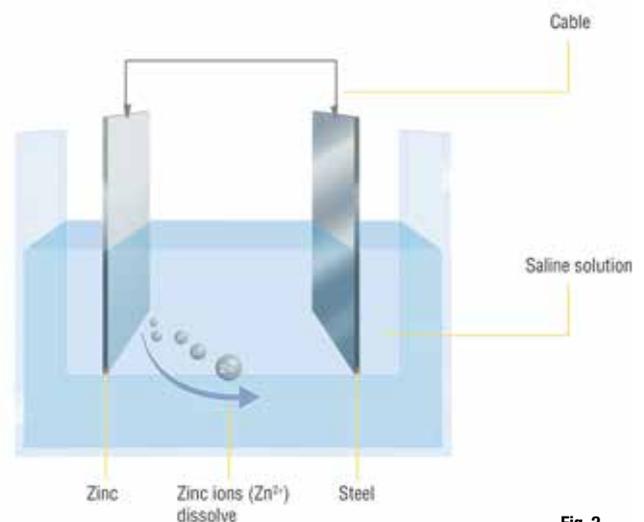

Cable

Saline solution

Zinc   Zinc ions (Zn²⁺)   Steel
         dissolve

Fig. 2

The zinc acts as a "sacrificial anode", protecting the steel against corrosion by making it a cathode (in heating technology, sacrificial anodes are used to protect boilers and tanks, for example; galvanised vessels are protected with magnesium anodes as magnesium is more base than zinc). Therefore, electro-galvanised steel is not only protected by the passivated zinc layer (see below), even in the event that the zinc coating is damaged, it still has its sacrificial anode, so to speak. But of course, only for as long as the zinc sacrificial layer is there. Cathodic corrosion protection can also be achieved on a large scale, i.e. an entire system is provided with an electric charge (anode with a current from an external source, sacrificial electrode). On shipping vessels or offshore facilities, sacrificial anodes are distributed around the structure.

2.1.2 Passivation

If the zinc sheet is now replaced with a copper sheet (which is nobler than steel), the steel noticeably rusts more quickly because it has now become the anode (Fig. 3).
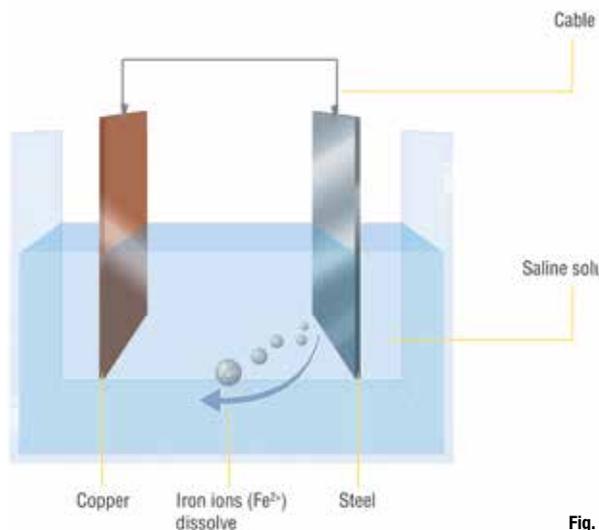

Fig. 3

However, the process slows with time because in the saline solution the copper tarnishes, becoming matt and dark, and loses its effectiveness as a cathode; it passivates as a result of a chemical reaction with constituents of the electrolyte or the air (in the case of copper, oxygen and carbon dioxide). Without the contact with the steel, this passivation of the copper occurs even more quickly because it does not function as a sacrificial anode. Passivation is therefore another type of corrosion process, but not a progressive one; the passivation layer is very thin (in the case of ferrous metals) and still electrically conductive to relatively thick (in the case of copper) and no longer electronically active (it is no longer a conductive metal, but an inorganic compound), and it can shield the metal so heavily at some point that the electro-chemical element disappears. With copper or bronze, the final stage is the green patina (mistakenly called "verdigris", see below), but there are some steels that can highly passivate (Cor-Ten steel, incorrectly referred to as "patina").

Passivation layers (also inaccurately called "cover layers") are firmly bonded to the metal and can only be mechanically removed by drastic means (blasting, grinding, cauterising), while rust or verdigris have a different chemical composition, peel off and thus allow the damage to the metal to continue. If there is a patina, phenomena such as rust, verdigris, metal disease and corrosion are less pervasive, if at all. Patination or anodisation ("tarnishing") is, therefore, another method of increasing corrosion protection. However, they have their limitations. Although passivation allows the reliable use of what are essentially base metals in critical environments, such as aluminium (which automatically tarnishes to a matt finish in contact with air or which can be anodised – in both cases the oxygen in the air helps form passivation layers) or zinc (passivated with oxygen and carbon dioxide). However, if the passivated base metal is combined with a significantly more noble metal and/or a strong electrolyte in an electro-chemical element, under certain circumstances, the passivation layer and subsequently the base metal can be broken down. Copper and aluminium should only really be combined if the third part of the galvanic element, the electrolyte, is excluded, e.g. a copper rivet in aluminium including the contact surface between the two metals is coated (Fig. 4).
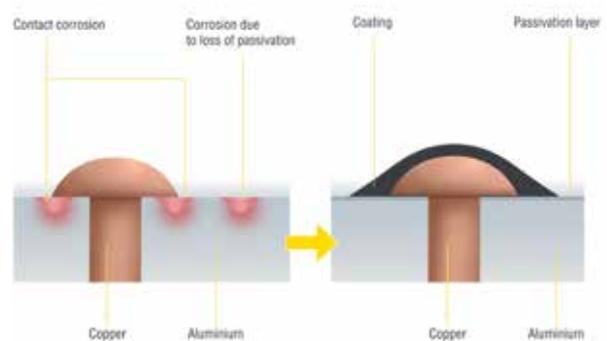

Fig. 4

Connecting a zinc to a copper gutter should be avoided where possible, and not just because of the visual appearance…

2.1.3 Oxygen and hydrogen corrosion

It is well known that an acidic environment or direct acidic conditions rapidly speed up the rusting of iron. Firstly, the acid increases the electrical conductivity and thus the effect of the electrolyte, and secondly, it absorbs the electrons given off by the anode (and thirdly, it may erode any passivation layers). If there is little or no oxygen in the chemical element, hydrogen is generated (hence hydrogen corrosion); acid can also be corrosive when there is no air present. Alkaline corrosion protection is therefore expedient under these conditions, e.g. in contact with water or earth.

If the hydrogen generated by the acid corrosion is not dissipated quickly enough, it can accumulate within the metal matrix (usually at the grain boundaries, see below) or react with the metal atoms, e.g. in non-austenitic steels and copper. This results in material fatigue, which manifests itself as cracks – hydrogen embrittlement (HIC, hydrogen induced corrosion cracking). This is not actually a real corrosion phenomenon, but its immediate result and, in terms of the mechanism, it is related to stress corrosion cracking (see below); because the hydrogen had been generated on the cathode of the chemical element, it is also known as cathodic stress corrosion cracking.

Oxygen corrosion requires air admission and usually occurs in neutral (water) or base (lyes) environments. However, depending on the composition of the chemical element, acidic oxygen corrosion is also possible and it will occur together with an alkaline parallel reaction. The rusting of iron is just such a complex process in which oxygen and hydrogen corrosion occur in a changing environment. Oxygen corrosion is by far the most common form, and it also includes the majority of passivation processes. It may be suppressed by cutting out moisture and/or oxygen, i.e. by means of (diffusion-) tight protective coatings.

2.1.4 Special types

Sometimes it is not necessary to have three, but apparently only two constituents to form an electro-chemical element. Many metals do corrode without any contact with a nobler metal, simply by coming into contact with (moist) air. They are either base and non-passivating metals (e.g. iron), that oxidise easily, or it occurs due to differences in the concentration of the electrolyte. The metallic portion of the higher concentration then acts as the anode and thus breaks down (metal ions go into solution), while the metallic portion of the lower concentration functions as the cathode where metal redeposits itself, albeit as a weak compound (Fig. 5).
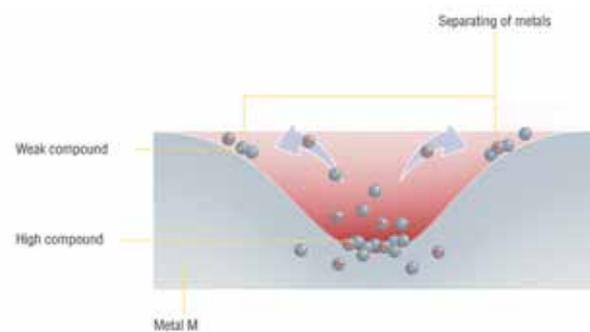

Fig. 5

This self-corrosion by forming a concentration cell occurs, for example, in moist or liquid-filled crevices, as differences in concentration almost always occur here (crevice corrosion), or if salts or acids can be found locally on the (moist) surface of the metal.

If a concentration cell is present, both hydrogen and oxygen corrosion can occur, e.g. hydrogen corrosion in a crevice because of too little air admission, with oxygen corrosion along its edge. This is why halogens (chloride, bromide) and sulphates are restricted or even prohibited in many specifications: they are effective electrolytes, create concentration gradients and are usually also acidic. Under certain circumstances, they are also capable of attacking passivation layers and facilitating pitting corrosion (see below).

2.1.5 Optical manifestations of classic corrosion

Changes of colour can, but do not always, indicate corrosion. In the scenario with copper illustrated above, discolouration and becoming matt is also a sign of passivation. However, with ferrous metals, the situation is clearer: anything reddish in colour is suspect. In stainless steel this can also include dark spots with a reddish or brownish tinge. This makes it easier to identify corrosion, although countermeasures are required immediately, because with ferrous metals in particular, rapid progress is to be expected.

The most harmless form of corrosion is uniform corrosion: it occurs on a large scale but doesn't penetrate deep into the metal. Typical of uniform corrosion is that the area currently undergoing corrosion migrates across the surface, with some areas acting as the anode and others as the cathode. Only once the whole area has been corroded through or any creeping of the anode/cathode areas is prevented (e.g. by flanges, fittings or transitions) does the corrosion turn inwards and become shallow pit corrosion. However, the overall material loss here is also very limited. Leaks resulting from shallow pit corrosion only really occur if the overall installation has essentially been incorrectly designed and/or installed. A shallow pit that becomes a hole is not pitting corrosion (see below), but the result of extensive local damage.

Real pitting corrosion is justifiably feared. It only affects passivated metals, i.e. not iron, but suitable steels, aluminium, etc. Halogens, or more precisely halogenide ions (and only the water soluble ones) and sulphides can replace the oxygen in passivation layers that have built up as a result of reacting with oxygen (oxidation). Additional halogenides or sulphides tend to build up in the vicinity of a location that has already been replaced and thus destroy the passivation layer at a small point (Fig. 6).
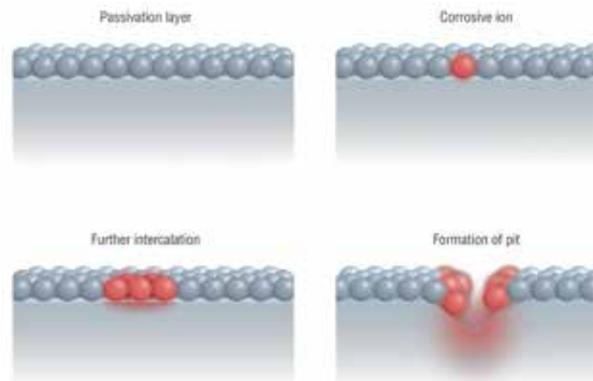

Fig. 6

It is difficult for oxygen to penetrate into this "germ of a hole" and thus almost impossible for it to repassivate. However, moisture can penetrate and a concentration cell is formed, as we learned above. There is little oxygen along the edge of the hole but a lot of halogenide/sulphide, while in the hole there is no oxygen and hardly any halogenide/sulphide. In any case, there is a concentration differential which leads to corrosion. Particularly deceptive is that the entire surface of the metal forms the cathode, but only the tiny edge of the hole acts as the anode. However, because the cathode "eats" the anode (or more accurately, the speed of corrosion increases with the increase in anode/cathode surface ratio), the hole quickly gets larger and, more important, deeper. A germ of a hole can hide a real cavity. Pitting can just as easily occur from the inside as well as from the outside, e.g. with chlorinated water in austenitic steel pipes, with sulphatic water in copper pipes, in an aggressive environment (chlorinated or saline, damp air, hydrogen sulphide/sulphurous traces, e.g. from natural gas, agriculture, industry), etc.

Leaks resulting from classic corrosion are rarely spontaneous and large-scale, but occur gradually and locally. In contrast to corrosion cracking (see below) it is still possible to attempt repairs to damaged installations with a good probability of success, as classic corrosion (under normal conditions with the exception of extensive pitting) only progresses at a rate of around 1 mm wall thickness per year.

2.2   Corrosion cracking

Shallow pits or holes are visible signs of classic corrosion, which work from the surfaces into the material. In contrast, corrosion cracking occurs within the composite material it-self and only then becomes visible – as cracks, leaks or even structural failure – when it is too late. The damage can thus begin months or even years before it becomes visible.

2.2.1 Inner- and intercrystalline processes

As we saw at the beginning, metals all have the same struc-ture on the atomic level, comprising metal atoms and the electron gas that surrounds them. However, go up a level, and there are noticeable differences: metals are made of crystallites, in other words, superordinate, crystal-like struc-tures that take on a different size and shape depending on the metal or alloy. Within a crystallite, the metal atoms are arranged completely homogeneously, and again homogene-ously within the next crystallite, but differently to the other crystallites. This can be imagined as a foam sheet with many round cells of the same size (that represent the metal atoms). If the sheet is cut into pieces and glued back together again, as in Fig. 7, from the outside, it looks like a foam sheet again, but when examined more closely, it now comprises different areas, each of which is homogeneous in its own right.
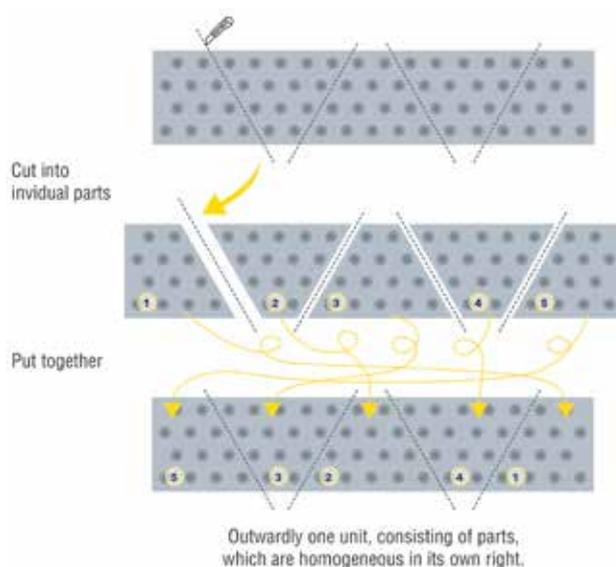

Cut into invidual parts

Put together

Outwardly one unit, consisting of parts, which are homogeneous in its own right.

Fig. 7

Crystallites or grains exhibit grain boundaries. These are transitions to the next grain where there are slight disparities in the electron gas and thus essentially weak points where corrosion processes can attack. This is known as intercrys-talline corrosion (grain failure). But the metal composite can also disintegrate within a grain, i.e. innercrystalline or transcrystalline corrosion can take place. Grain failure must always be considered wherever crystallites are particularly pronounced – in alloys.

2.2.2 Stress cracks

Stress corrosion cracking (SCC) is the disintegration of the inner metal composite (with greater or lesser proportions of inter- and transcrystalline processes depending on the alloy) in the presence of

- vulnerable alloys,
- stresses (tensile, bending or deformation stress, and even internal stress) and
- specific corrosion media, as well as
- high temperatures; SCC reactions are very slow or stop below +50 °C. The formation of cracks in cooling lines must, therefore, generally be due to other reasons.

Pure or almost pure metals are thus impervious to stress corrosion cracking, while certain combinations of alloys and corrosive materials can be extremely critical:

- Zincnitrogen/ammonia alkali. Zinc in alloys, especially those containing copper (brass, red brass, bronze) is sen-sitive to nitrogen compounds, especially ammonia and its derivatives (amines, amides, ammonium compounds, ni-trite, nitrate) and also nitrogen oxides. If the zinc is trans-formed, the alloy loses its internal cohesion.
- Zincsulphur/SO_2. Sulphur dioxide and sulphur compounds that form or contain sulphur dioxide, and also to a certain extent sulphides, can attack the zinc in alloys.
- Austenitic steels-halogenides. Halogenides, and chlorides in particular, can change or dissolve out those alloy con-stituents (chrome, molybdenum) in rust-resistant steels that ensure the passivation. Holes form in the protective

layer of chrome or molybdenum oxide and the corrosion penetrates between and within the crystallites.

- Low- or non-alloyed steels and alkali hydroxides (caustic soda). The aggressive lye corrodes passivation layers and converts the iron itself – usually at the grain transitions.

Although SCC starts on surfaces, the main processes play out in the deeper layers. In non-ferrous alloys, the intercrystalline fracture usually plays a bigger part, while in steels it is the transcrystalline. The typical crack pattern helps differentiate SCC from purely mechanical stress cracks, crevice corrosion or pitting.

2.2.3 Fatigue cracks

With SCC, vibrations in the components can speed up the phenomenon. On the other hand, vibrations can also dissipate stresses and reduce the risk of SCC to a certain degree. However, corrosion cracking can also occur in stress-free installations, caused by the following factors:

- Temperature and
- Movements instead of stresses, and partially
- Critical alloy/corrosion media combinations

that create corrosion fatigue cracking (CFC). CFC can also affect non-alloyed, pure metals if they are thus mechanically prone. The reaction then starts out as crevice corrosion in micro-cracks. Moved parts such as pistons, valves and shafts, but also installations that experience vibrations of all kinds due to motor or flow movements are at risk.

The chemical mechanism of the corrosion fatigue cracking is identical to that of the SCC. However, due to the mechanical loads of the materials, it occurs sooner at the same level of exposure and this increases the risk of sudden failure. It is usually the transcrystalline fracture that dominates.

2.2.4 Hybrid forms

As the corroding media involved in the corrosion cracking also have the potential for classic corrosion, in reality there are several processes occurring at the same time or alter-

nately. As pitting begins in a very similar manner to corrosion cracking, i.e. with a point of attack to the passivation layer, if pitting is present in alloys suspected of SCC, it is always necessary to check whether stress cracks will occur on the basis of the hole. In the case of crevice corrosion on moving parts, it is also always necessary to consider the more deeply penetrating CFC.

As mentioned at the beginning, the contact between metals of very different noble characters (also known as the redox potential) is always critical. However, the combination of different metals with a similar redox potential can also cause considerable risks. Steels thus almost always contain sulphides that could lead to corrosion cracking if they come into contact with copper alloys. In general, the corrosion behaviour of steels – in combination with non-ferrous metals or even other steels – should not be underestimated. One type of steel can build up such a high redox potential in relation to another that it can make it an anode, while high-alloyed special steels can fail in the simplest of applications because, under standard conditions, they are vulnerable to the slightest traces of chemicals.

2.2.5 Optical manifestations of classic corrosion

Corrosion cracking does not cause discolourations or matting. However, changes to surfaces can be a sign of generally unfavourable conditions. In the presence of halogenides and sulphides, the majority of steels can become matt and often darker, and copper alloys dull and almost black if in permanent contact with sulphide. If cracks occur – initially hairline cracks in the direction of stress, then rapidly spreading – the affected installation – as is the case with pitting – must be replaced as it is impossible to estimate how deeply the structure has been damaged. The fine crack on the outer surface can spread internally in the shape of a funnel until it reaches the inner surface. In any event, the crack branches internally breadthwise; heavily in the case of SCC, less so with CFC. With corrosion cracking, leaks are therefore spontaneous and serious.

2.3   Non-metallic corrosion phenomena

Even plastics are capable of corroding if the necessary unfavourable conditions are present. In an alkaline environment, stress corrosion cracking can occur in thermoplastics (PE, PP, PVC, i.e. typical pipework materials), because they have crystalline areas that can be attacked in a similar manner to crystallites, and because they are rigid enough to contain stresses. Elastomers (rubber) dissipate stresses and therefore cannot corrode.

However, damage to plastics (thermoplastics, duromers and even elastomers) through contact with corroding metals is significantly more frequent. As shown above, aggressive substances (metal ions, metal halogenides, salts, etc.) occur as a result of corrosion of and with the metal, which are largely soluble and which can migrate across the surfaces of plastics, where they react. These "metal soaps" (because they contain "hard" metal ions and can actually saponify plastics, i.e. split them) are capable of attacking hard and soft plastics and elastomers in a similar damage pattern to shallow pit or pitting corrosion. As a result, thermoplastics can also experience stress corrosion cracking, while elastomers, depending on the attacking substance and environmental conditions, experience brittleness or softening. In extreme cases, plastics can be completely dissolved by aggressive byproducts of corrosion.

3.   Corrosion in practice

3.1   Relevant examples of corrosion

Corrosion is everywhere, and when you hear the term, you naturally immediately think of pipework red with rust and car bodies that have been eaten away, etc. But it is hidden corrosion that can have enormous implications. Mercury is normally prohibited on board planes because even the slightest trace of the noble but liquid and therefore highly wetting metal forms a compound with the aircraft aluminium (aluminium amalgam), resulting in an electro-chemical element that can

cause total structural collapse. But even very high-grade, noble alloys are not without their dangers. Medical implants and body jewellery (piercings) can suffer corrosive damage similar to pitting corrosion) due to chlorides and amines in blood or sweat (and can also transmit harmful ions (nickel, chrome) into the body.

3.2   Corrosion under insulation

Corrosion processes under thermal or acoustic insulation (CUI – corrosion under insulation) belong to the hidden and therefore particularly critical damage processes. Cooling and refrigeration systems, and those that change temperatures are particularly vulnerable, i.e. installations that tend to draw ("pump") (moist) air through the insulation while in operation.

For this reason, the insulation has to meet several requirements in order to prevent CUI.

- It must be chemically neutral, i.e. have a pH value of 7 in order that it does not facilitate either acid or alkaline corrosion.
- It must not give off critical ions (i.e. it may contain chloride, sulphides, etc. but they must not be in a soluble form).
- It must have a suitable vapour barrier effect depending on the application in order to prevent moisture condensation.

With regard to this last point in particular, it is important to pay close attention to the insulation products and the combinations thereof. An insulation that completely blocks vapour only exists in theory! While foamed glass has an infinite water vapour diffusion barrier value (my value), this material unfortunately has many joins and these are weak points. They themselves are not impervious and have a tendency to shrink and form cracks, i.e. create diffusion bridges. Fibre insulation products (e.g. mineral and glass wool) are almost entirely breathable and at risk of becoming soaking wet, just like resin-based foams that are either open cell, i.e. breathable, and/or hydrophilic materials, which are absorbent by nature.

3.3 Insulation products for corrosion-critical installationsn

Use of the terms "vapour barrier" or "vapour barrier film" for thermoplastic materials is essentially incorrect. While the theoretical diffusion tightness of a material is determined by the my value (the higher the better), the actual vapour barrier effect is given by the so-called diffusion-equivalent air layer thickness, the SD value. This is the my value of the material multiplied by the thickness of the material and is given in metres. A PE or PET film that is been advertised as a "vapour barrier" has a thickness of perhaps 100 micron, i.e. 0.1 mm or 0.0001 metres. Even if such films are advertised with my values of 100,000, their real SD value at 10 metres is no greater than that of an elastomeric insulation material of just one millimetre and my = 10,000! Or, an elastomeric cladding with my = 50,000 and a thickness of 1 mm provides just as much of a vapour barrier effect as 5 layers of film (see Fig. 8) and is simpler, safer and quicker to install.

The only realistically usable vapour barriers are real metallic films (metallising on its own is not enough), and these have their risks in terms of handling and adhesion. There must not be any holes or joins, otherwise the installation draws in water through these points. A good, if expensive, alternative is thick aluminium-thermoplastic composite films which exist with fabric inlays for strengthening and self-adhesive backing (see Fig. 8). However, you should never rely solely on the vapour barrier; the insulation products must also provide some security.

4 x 25 mm
Kaiflex KKplus
S_D = 1.000 m

Foils
5 x (S_D = 10 m) = 50 m
$\Sigma\, S_D$ = 1.050 m

Protect (R) HD
S_D = 50 m
$\Sigma\, S_D$ = 1.050 m

Kaiflex Protect Alu-TEC
S_D = 100 m
$\Sigma\, S_D$ = 1.100 m

Fig. 8

4. Corrosion protection and insulation

Insulators must be aware of the corrosion risk. They are, after all, responsible for the "I" in CUI. AGI Worksheet Q 151 "Corrosion protection under insulation" provides valuable advice on how preventative corrosion protection should look before the insulation is applied and must be taken into consideration because it represents an acknowledged rule of technology. Failing to observe it can therefore lead to serious claims regarding loss of insurance cover and legal security. This also applies if the corrosion protection has not been carried out by the insulator, but if faults are determined with the existing paintwork or coatings and these have not been reported or remedied.

4.1 Protecting metal

With pipework, corrosion protection usually involves the application of a coating. The purpose of this is to keep moisture, harmful ions and, if possible, oxygen at bay from the metal, but it must also be applied in a sufficiently thick and encompassing layer to all metallic parts. The type of metal doesn't matter. As has been shown in detail above, all alloys are prone to corrosion in one way or another.

Viable corrosion protection coatings must therefore adhere equally well to and function with ferrous and non-ferrous metals, which usually requires an application of multiple-layers. It is an advantage if the individual constituents are of different colours, as this makes it possible to visually check

the progress and sufficient coverage (see Fig. 9). Each layer of epoxy and polyester (PU) systems must comprise two constituents, whereas coatings with alkyd or acrylic resin binder have a single constituent and are therefore quicker to apply. However, the coating on its own is not enough. It is also necessary to check the compatibility, in both directions, of the insulation product to be applied, and with the appropriate insulation adhesive in order to rule out the softening of the coating binder or any changes to the adhesive or insulation product.
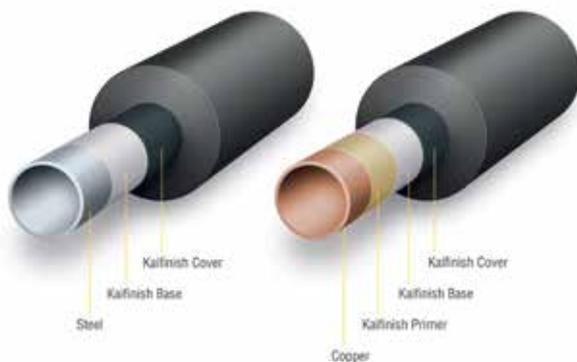

Fig. 9

4.2   Correct insulation design

As illustrated above, an insulation product with a vapour barrier is, depending on the application, an important or even essential component of preventative corrosion protection. Apart from cellular glass foam, elastomeric insulation products have the highest my values on average. As rubber is usually water resistant (hydrophobic), as a foam it offers the best prerequisites for reliable cooling and varying temperature insulation products if correctly applied, i.e. sealed with synthetic rubber adhesives.

Depending on the application, elastomeric insulation products (FEF) can be applied directly to the installation (protected against corrosion by a coating) or in multiple layers with water vapour barriers. As it is never possible to achieve a completely water-tight metallic covering, we recommend applying an elastomeric cladding as an external layer. In

extreme temperatures it is consequentially worth applying a combination of an inorganic internal layer with a casing of FEF, whereby the dew point must lie within the FEF.

5   Conclusion

Corrosion protection is an important element of a permanently effective insulation and must be installed professionally and securely. The whole system depends on the insulation product used.

The coatings of the Kaifinish corrosion protection system comprise a single constituent, making them easier and quicker to apply. Their different colours ensure that it is easy to perform a visual progress check at any time.

Installers and operators are thus on the safe side.

List of references

Mentioned standards

[a]   DIN EN ISO 8044:2015-12
  "Corrosion of metals and alloys –
  Basic terms and definitions"
[b]   AGI Worksheet Q 151
  "Corrosion protection under insulation materials"

Annotated list of references

[1]   Kunze (publisher): Korrosion und Korrosionsschutz [Corrosion and corrosion protection], 6 volumes., Weinheim 2001.
  Standard reference work with almost 3,800 pages, very comprehen-sive, but due to the number of authors, not very homogeneous in writing style and not all of the same period.

[2]   Kaesche: Die Korrosion der Metalle [The corrosion of metals], Berlin 1990.
  No longer current, but very readable: each chapter can be read inde-pendently without having to work through the book from cover to cover.

[3]   Trostmann: Korrosion – Ursachen und Vermeidung [Corrosion – causes and prevention], Weinheim 2001.
  Based on the transcript of a lecture and therefore somewhat aca-demic but more concentrated and rigorous than [1].

[4]   Winnik (publisher): Corrosion-Under-Insulation (CUI) Guidelines: Revised Edition, Cambridge 2016.
  Part of a large series on corrosion; very good practical bias.

[5]   Schweitzer: Corrosion of Polymers and Elastomers, Boca Raton 2007.
  "Corrosion" here refers in general to the damage to plastics, including real corrosion. Complete overview.

[6]   Raja, Shoji: Stress corrosion cracking – Theory and practice, Cambridge 2001.
  Comprehensive, up-to-date overview of SCC.