Galvanic corrosion in domestic installations

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Abstract

The use and combination of various metals in domestic drinking water installations can result in galvanic corrosion problems. While the principle issues of galvanic corrosion are well understood, protective measures are taken into account only to a limited extent. This is also partly related to specific water properties and the formation of covering layers, which may influence the corrosion velocity considerably. The general principles of the corrosion issue are presented and specific solutions are presented.

Zusammenfassung

Der Gebrauch und die Kombination von verschiedenen Metallen in Trinkwasser-Hausinstallationen können zu erheblicher Korrosion aufgrund der Bildung von galvanischen Elementen führen. Die grundlegenden Prinzipien der galvanischen Korrosion sind zwar gut verstanden, die daraus abzuleitenden Schutzmassnahmen werden aber oft nur sehr beschränkt berücksichtigt. Dies ist teilweise auch auf die Auswirkungen der Wasserzusammensetzung und der Bildung von Deckschichten zurückzuführen, welche die Korrosionsgeschwindigkeiten stark beeinflussen. Die generellen Prinzipien der beteiligten Korrosionsprozesse sowie konkrete Lösungen werden diskutiert.

Résumé

L'utilisation et la combinaison de différents métaux dans les installations domestiques peuvent engendrer des problèmes de corrosion galvanique. Quoique les principes de la corrosion galvanique sont bien connus, des mesures de protection ne sont appliquées que de façon limitée. Ceci concerne également les propriétés spécifiques de l'eau et la formation de couches couvrantes qui ont une influence importante sur les vitesses de corrosion. Les principes généraux du problème de la corrosion sont présentés, ainsi que les solutions spécifiques.

1. Introduction

At present, a wide variety of materials is available for domestic drinking water installations. However, combinations of different materials might under certain conditions lead to heavily accelerated corrosion and thus cause damage (leakages) within a few years. These effects are highly relevant for new buildings and in particular for extensions or repair work of existing drinking water installations. The present paper discusses the principles of galvanic corrosion as well as specific solutions to minimize damages caused by internal corrosion in domestic drinking water installations.

2. The principle of corrosion

Corrosion in drinking water systems takes place as an electrochemical interaction between a metal and its environment. This process changes the properties of the metal and might thereby considerably affect the functionality of the metal, its environment or the technical system.

The electrochemical corrosion process occurs in two separate partial reactions: On the one hand, the metal undergoes anodic oxidation, viz. the metal atom is dissolved from the solid metal lattice. Thereby, it is transferred into the liquid phase (electrolyte) as a positively charged ion while releasing two electrons (that remain in the solid metal) according to equation (1) (written for the case of iron):

$$Fe \rightarrow Fe^{2+} + 2e^- \tag{1}$$
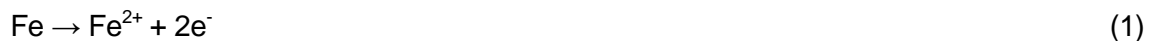
On the other hand, cathodic oxygen reduction takes place according to equation (2):

$$O_2 + 2\,H_2O + 4\,e^- \rightarrow 4\,OH^- \tag{2}$$

To satisfy the electroneutrality condition, the rates of iron oxidation and oxygen reduction must be equal – in other words: the number of electrons generated in the anodic oxidation reaction must at any time be equal to the number of electrons consumed in the cathodic reduction reaction. This relation is schematically depicted in Fig. 1 where the size of the arrows represents the rate of the corresponding reaction. The anodic process is shown as red arrows leaving the metal, while blue arrows entering the metal indicate the cathodic process.

On certain metals, formation of a protective layer of oxides can lead to passivation. In this case, the corrosion process (viz. the anodic reaction) is decreased to a negligibly low level. An example of a passive metal in drinking water systems is stainless steel.
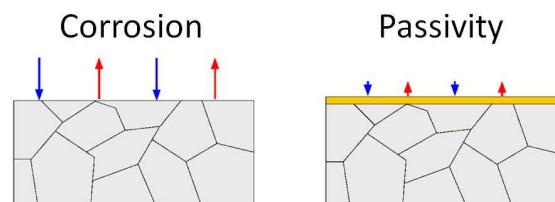

Fig. 1   **Electrochemical reactions occuring on the metal surface (blue = reduction reaction, red = oxidation reaction). Left: Non-passive, corroding metal; right: passive layer (yellow) decreasing the electrochemical reactions.**

At the interface of a material in contact with an electrolyte (e.g. water), an electrochemical potential is established. The potential depends on material, concentrations of dissolved oxygen

and metal ions in the electrolyte, as well as the formation of passive and other protective layers. The potential is generally referred to as "corrosion potential". Table 1 gives a few examples of corrosion potentials of different metals in potable water.

Table 1:   Examples of corrosion potentials of different metals in potable water

Metal	Potential [V CSE]
Copper	-0.10
Stainless steel	-0.10
Red-bronze and Si-bronze	-0.20
Brass	-0.35
Iron in aerated water	-0.55
Iron in stagnant water	-0.75
Galvanized steel	-1.0

In case of an electrically conductive connection between two metals of different potential, a galvanic cell is established. While reduction of oxygen can occur on both metals, oxidation takes primarily place on the metal exhibiting the lower potential. This accelerates the process of metal dissolution (corrosion) on the structural element with the more negative potential. The effect of acceleration is more pronounced, the higher the surface area ratio of the two metals is (please note that only the surface area in contact with water is relevant in this context). Thus, it is particularly unfavourable to have a configuration with a small anodic structural element (lower potential) in contact with a relatively large cathodic structural element (higher potential). In extreme cases, such a configuration can give rise to corrosion rates up to 2 mm/year.
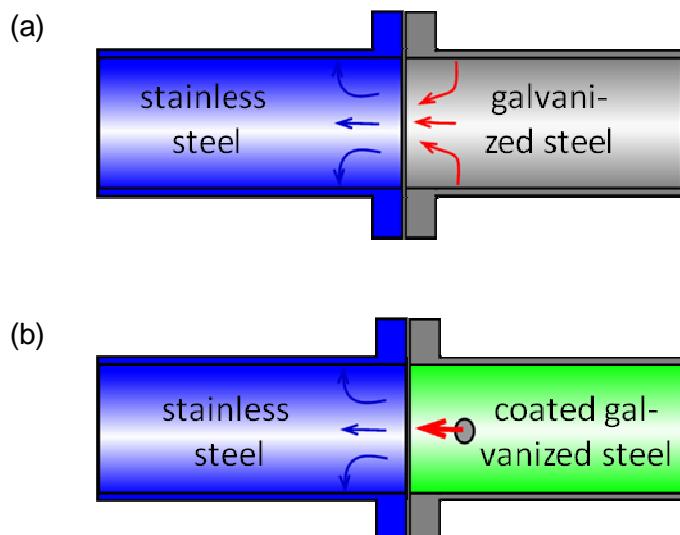
(a)

(b)

Fig. 2:   Combination of stainless steel (blue) and galvanized steel (grey): a) without internal coating, b) with an internal coating (green) on the galvanized steel.

Examples of unfavourable material combinations are shown in Fig. 2. Owing to the different electrochemical potentials of stainless steel and galvanized steel as well as an electric and

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electrolytic (water) contact between the two materials, a galvanic element is established that accelerates the corrosion rate of the galvanized steel (Fig. 2a). An internal coating such as a synthetic resin applied to the galvanized steel would locally even increase the corrosion rate, since the entire anodic process (metal dissolution) is confined to the defect in the coating, thereby leading to a high corrosion rate (Fig. 2b).

3. Mitigation of galvanic corrosion

The following possible solutions to minimize the risk of galvanic corrosion in domestic drinking water systems are in principle applicable to galvanic corrosion problems in general. The examples are discussed for the case of a combination of galvanized steel and stainless steel.

3.1. Galvanic separation

A possible solution of the problem of galvanic corrosion is to electrically separate the materials. This can be achieved by the use of insulating flanges or muffs that interrupt the electric current flow between the different metals. In practice, these insulating points are, however, often bypassed for several reasons: First, an electrical connection between the different parts of the drinking water installations is required for safety reasons (equipotential bonding). Second, electric contacts might accidentally be present in the system and short-circuit different parts of the installations. The use of insulating flanges or muffs is thus often only a feasible solution for separating single devices, an example of which is given in Fig. 3. A water meter, made from cast iron and internally coated, is integrated in a stainless steel pipe; galvanic separation is achieved by insulating flanges. Although the water meter is bypassed, it does in this case not lead to galvanic corrosion as long as the water meter itself is not electrically connected to the potential bonding.
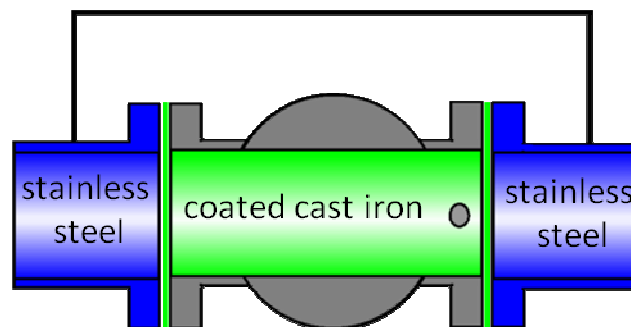

Fig. 3: **Galvanic separation of a cast iron water meter (grey) and a stainless steel pipe (blue) by insulating flanges (green). The internal coating of the water meter is also shown in green.**

3.2. Installation of an insulating section

The harmful effect of a galvanic cell can not only be reduced by electrically separating the involved materials, but also by increasing the electric resistance in the electrolyte. This is for instance achieved by incorporating an electrically insulating section between the material parts that have different electrochemical potentials. The required length of the insulating section depends on water conductivity, pipe diameters and the potential difference between the metals. Insulating sections in drinking water installations should typically have a length of at least 5 times the pipe diameter. There are essentially two options for insulating sections, as schematically depicted in Fig. 4 for the example of a stainless steel pipe in connection with a pipe of galvanized steel.

- A plastic pipe is inserted between the stainless steel pipe and the galvanized steel pipe (Fig. 4a)

- The stainless steel pipe, viz. the more noble material, is internally coated on a certain length as well as on the flange (Fig. 4b)
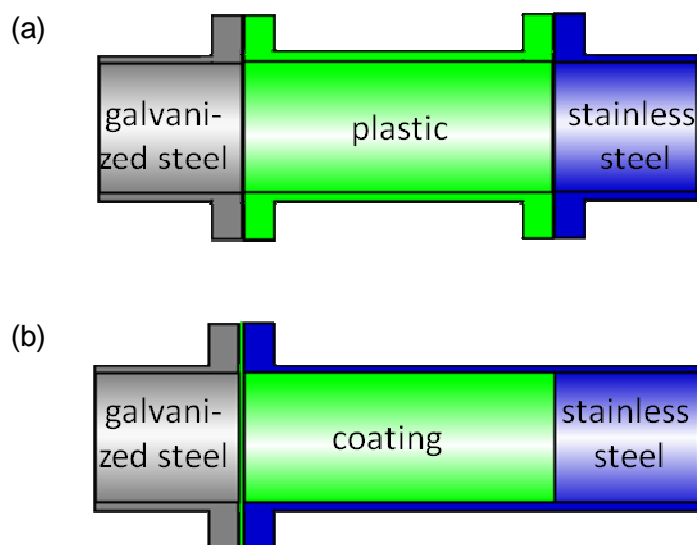
(a)

(b)

Fig. 4: **Combination of a stainless steel pipe (blue) and a galvanized steel pipe (grey) with an insulating section; a) plastic pipe (green), b) internal coating (green) of the stainless steel pipe and its flange**

4. Operational influences and general experience

4.1. Direction of water flow

For the case of copper and copper alloys, it is worth mentioning that copper based pipes should always be placed after galvanized steel when considering the direction of the water flow. Otherwise, there is an increased risk of pitting corrosion on the galvanised steel parts. In case of single devices made from brass, red-bronze or Si-bronze, the risk of pitting corrosion on the galvanized steel is often much smaller and can be neglected.

4.2. Water composition

Experience has repeatedly shown that combinations of metals with different corrosion potentials do not necessarily lead to galvanic corrosion. This can often be explained by the formation of a thin, insulating layer of calcium carbonate, which is deposited on the more noble metal. Formation of this layer is favoured by the pH increase occurring at the cathode as the result of oxygen reduction according to reaction (2). This affects the lime-carbonic acid-equilibrium in such a way that precipitation of calcium carbonate occurs.

4.3. Use of red-bronze fittings

In the past, it was common to use elements of red-bronze between sections of stainless steel and galvanized steel pipes. This might decrease the potential difference of the galvanic cell (Table 1) and thereby reduce the corrosion rate. Nevertheless, experience has shown corrosion-related deterioration of such cases, in particular when the water composition prevented formation of an insulating layer on the red-bronze. This approach is thus not considered as a reliable method of corrosion protection.

4.4. Alloy composition of stainless steel

A variety of stainless steel alloys are presently admitted to be used for drinking water installations. Electric contacts between different stainless steel alloys do not accelerate corrosion, even in the case of different corrosion potentials. The protective passive layer prevents corrosion and mitigates the galvanic cell.

5. Conclusion

Galvanic corrosion can cause severe damages in domestic installations. The growing number of different materials being used increases the risk of corrosion. This is especially true when replacing parts of the existing piping made of galvanized steel.

The presented mitigation measures allow eliminating the problem of galvanic corrosion without compromising the safety of electrical installations.