BRITISH STANDARD

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Protection of metallic materials against corrosion — Guidance on the assessment of corrosion likelihood in water distribution and storage systems —

Part 4: Influencing factors for stainless steels

The European Standard EN 12502-4:2004 has the status of a British Standard

ICS 23.040.99; 77.060; 91.140.60

British Standards

National foreword

This British Standard is the official English language version of EN 12502-4:2004.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/8, Corrosion of metals and alloys, which has the responsibility to:

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Korrosionsschutz metallischer Werkstoffe - Hinweise zur Abschätzung der Korrosionswahrscheinlichkeit in Wasserverteilungs- und speichersystemen - Teil 4: Einflussfaktoren für nichtrostende Stähle

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Contents

Foreword

This document (EN 12502-4:2004) has been prepared by Technical Committee CEN/TC 262 “Metallic and other inorganic coatings”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2005, and conflicting national standards shall be withdrawn at the latest by June 2005.

This standard is in five parts:

Part 1: *General*;

*Part 2: Influencing factors for copper and copper alloy*s;

Part 3: Influencing factors for hot dip galvanized ferrous materials;

Part 4: Influencing factors for stainless steels;

Part 5: Influencing factors for cast iron, unalloyed and low alloyed steels.

Together these five parts constitute a package of inter-related European Standards with a common date of withdrawal (dow) of 2005-06.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

This document mainly results from investigations into and experience gained of the corrosion of stainless steel materials used as tubes, fittings or vessels in drinking water distribution systems in buildings. However, it can be applied analogously to other supply water systems.

The corrosion resistance of products made of stainless steel immersed in waters exists because of the presence of a very thin passive layer. Stainless steels in water systems are, in general, resistant to corrosion, although there are certain conditions under which they can sustain corrosion damage.

As a result of the complex interactions between the various influencing factors, the extent of corrosion can only be expressed in terms of likelihood. This document is a guidance document and does not set explicit rules for the use of stainless steels in water systems. It can be used to minimize the likelihood of corrosion damages occurring by:

- assisting in designing, installing and operating systems from an anti-corrosion point of view;
- evaluating the need for additional corrosion protection methods for a new or existing system;
- assisting in failure analysis, when failures occur in order to prevent repeat failures occurring.

However, a corrosion expert, or at least a person with technical training and experience in the corrosion field, is required to give an accurate assessment of corrosion likelihood or failure analysis.

NOTE Stainless steels are used for domestic pipework, in the food industry and, more importantly, in the chemical industry covering a variety of aggressive environments and service conditions. This explains the existence of a significant number of steel grades each with specific corrosion resistance and also specific mechanical properties.

1 Scope

This document gives a review of influencing factors of the corrosion likelihood of stainless steels used as tubes, tanks and equipment in water distribution and storage systems as defined in EN 12502-1.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 8044:1999, *Corrosion of metals and alloys — Basic terms and definitions (ISO 8044:1999)*.

EN 12502-1:2004, *Protection of metallic materials against corrosion — Guidance on the assessment of corrosion likelihood in water distribution and storage systems — Part 1: General*.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 8044:1999 and EN 12502-1:2004 apply.

4 Materials

For the purpose of this document, the term “stainless steel” includes all martensitic, ferritic, austenitic-ferritic and austenitic steels conforming to the requirements of EN 10088-1 [2], EN 10088-2 [3] and EN 10088-3 [4].

Examples of steel grades that are used or that can be considered as candidate materials for supply water installations are listed in EN 10312 [5].

This document also applies to stainless casting alloys, which are commonly used for the production of valves and fittings and which are of the same composition type as the steels listed in EN 10088, Parts 1 to 3. The casting alloys can be considered as equivalent to their wrought counter parts, provided that no sensitization of the material remains after manufacturing (to be checked by testing the resistance against intergranular corrosion).

5 Types of corrosion

5.1 General

The most common types of corrosion are described in EN 12502-1:2004, Clause 4.

The rate of uniform corrosion of stainless steels in water distribution and storage systems is negligible because of their passive state.

Under the conditions prevailing in water systems stainless steels are usually the more noble materials and hence are not endangered by bimetallic corrosion.

The likelihood of intergranular corrosion is negligible in the systems under consideration.

Discoloration of the material’s surface resulting from deposition of foreign corrosion products is not indicative of corrosion of the stainless steel.

In some cases, however, the passive layer of these materials can be locally destroyed. This can result in localized corrosion attack, which can lead to failure because of corrosion damage.

The types of corrosion considered for stainless steels comprise the following:

- pitting corrosion;
- crevice corrosion;
- stress corrosion;
- knife-line corrosion;
- corrosion fatigue.

For each type of corrosion, the following influencing factors (described in EN 12502-1:2004, Table 1 and Clause 5) are considered:

- characteristics of the metallic material;
- characteristics of the water;
- design and construction;
- pressure testing and commissioning;
- operating conditions.

5.2 Pitting corrosion

5.2.1 General

Pitting corrosion occurs only when the potential is more noble than a critical value, which is referred to as pitting initiation potential. The pitting initiation potential depends on parameters related to both the material and the water composition. Pitting corrosion can occur only if the redox-potential of the water is more positive than the pitting initiation potential.

5.2.2 Influence of the characteristics of the metallic material

The likelihood of pitting corrosion in stainless steels decreases with increasing chromium, molybdenum and nitrogen contents. It is increased for sulfur-enriched stainless steels (e.g. free-cutting stainless steels used for valves and fittings).

Clean metal surfaces exhibit the smallest likelihood of pitting corrosion.

Mechanical damage to the surface of finished products, e.g. by scratching or coarse grinding, results in an increased susceptibility of stainless steels to pitting corrosion and stress corrosion cracking.

Metallic particles of unalloyed and low-alloy steels can become embedded in the stainless steel surface during machining or handling. They can act as small anodes of corrosion cells, the cathode of which is the stainless steel. In the course of the dissolution of the anodes, the local concentration of chloride ions will be increased by ion migration, and therefore the likelihood of pitting corrosion increases. Furthermore, the corrosion likelihood can also be increased by the iron (III)-bearing corrosion products formed during the dissolution of the anodes, because these corrosion products are more effective oxidizing agents than the dissolved oxygen and favour the conditions necessary for the occurrence of pitting corrosion.

Sensitization can also lead to an increase in the likelihood of pitting corrosion. Incorrect heat treatment or welding procedures, where the material remains for a prolonged period of time in the temperature range of

500 °C to 800 °C leads to precipitation of chromium-rich carbides at the grain boundaries and consequent depletion of chromium in the vicinity of the boundaries. This change in the material is referred to as sensitization.

Sensitization can be revealed by testing in accordance with EN ISO 3651-2 [6]. Materials in the as-fabricated condition should be resistant to this test. Sensitization during fabrication and welding, especially with wall thicknesses greater than 6 mm, can be avoided by following the recommendations from the material's manufacturer.

5.2.3 Influence of the characteristics of the water

The likelihood of pitting corrosion of stainless steels increases as the chloride ion concentration in the water increases, if the other service conditions remain constant.

The likelihood of pitting corrosion (within the limits of supply water) is either decreased or the pitting corrosion is not influenced by the presence of other anions.

The likelihood for pitting corrosion of non-molybdenum-bearing ferritic and austenitic stainless steels in cold water becomes high when the chloride ion concentration exceeds about 6 mmol/l. For hot water the limiting chloride ion concentration for these alloys is lower, possibly less than 1,5 mmol/l depending on other factors discussed in 5.1 to 5.6.

5.2.4 Influence of design and construction

The likelihood of pitting corrosion and crevice corrosion is increased by welding defects such as filler metal sagging, incomplete root pass, edge misalignment, open pores, weld metal splashing, slag residuals on both base and weld materials.

During the welding process, oxide films and scales can be formed that highly increase the likelihood of pitting corrosion. This can be avoided by gas-shielded welding methods, where attention is paid to proper supply and guidance of shielding and purging gas.

Oxide films that exhibit colours darker than that of straw strongly increase the likelihood of pitting corrosion. Removal of oxide films can be achieved by pickling (with pickling agents free from hydrochloric acid), fine grinding or shot peening, e.g. with glass beads. Under critical conditions (e.g. depending on material and water composition and temperature) even straw-coloured oxide films increase the likelihood of pitting corrosion.

A special problem arises during alignment of tubes by tack welding prior to final welding. This usually cannot be done with proper gas shielding, thus creating critical sites for pitting corrosion. This effect can only be avoided by pickling the system after welding.

The risk of sensitization can be minimized by avoiding any excessive heat input during welding and heating of material, e.g. in order to facilitate bending of pipes, unless it is followed by a full annealing of the material.

5.2.5 Influence of pressure testing and commissioning

If pressure testing is not carried out according to the recommendations given in EN 12502-1:2004, 5.5, so that residual water is left in the system after draining, the likelihood for pitting corrosion is increased. This is the result of evaporation of water leading to an increase in chloride concentration.

Because the initiation of pitting corrosion depends on the potential, the likelihood of corrosion of stainless steels increases as the redox potential of the water shifts to more noble values, e.g. as a result of the oxidizing disinfection of new pipe systems. If any installed equipment is to be treated with oxidizing disinfectants for a limited period of time, there will be no additional corrosion risk if the recommendations given in appropriate standards are followed.

5.2.6 Influence of operating conditions

5.2.6.1 Influence of temperature

The likelihood of pitting corrosion increases with increasing water temperature.

In addition, on surfaces where the direction of heat transfer is from metal to water at high wall temperatures, especially where local boiling occurs, the likelihood of pitting corrosion is also increased.

5.2.6.2 Influence of flow conditions

Pitting corrosion is favoured in stagnant waters. The likelihood of pitting corrosion is very small in high velocity waters.

5.3 Crevice corrosion

5.3.1 General

Crevices which are formed between two metallic materials or between a metallic and a polymeric material (e.g. for sealing reasons) can induce the formation of a concentration cell, which can lead to pitting corrosion within the crevice.

Crevice corrosion normally occurs at lower chloride levels and/or lower temperatures than pitting corrosion on bare surfaces.

5.3.2 Influence of the characteristics of the metallic material

The influence is similar to that discussed in 5.2.2.

5.3.3 Influence of the characteristics of the water

The influence is similar to that discussed in 5.2.3.

However, molybdenum-free steels can undergo crevice corrosion, even when the chloride ion concentration in the bulk solution is considerably lower than the values discussed in 5.2.3.

5.3.4 Influence of design and construction

Design parameters that create crevices enhance the likelihood of crevice corrosion. Crevices with a width greater than 0,5 mm are, in general, not critical. However, apart from width, the depth of a crevice is also important.

The susceptibility to corrosion increases, if sealing materials with contents of leachable chloride ions exceeding a mass fraction of 0,05 % are used.

Experience has shown that the susceptibility to crevice corrosion significantly increases when the stainless steel threads are in contact with plastic tapes.

A design that favours stagnant conditions (e.g. dead legs) or very low flow increases the likelihood of crevice corrosion. Deposits settle out particularly in horizontal areas. Deposits can be materials that enter the tube during installation process (e.g. swarf, loose scale moved on by the water, packing material, silt, sand). Precautions against the admission of such materials will decrease the likelihood of crevice corrosion, e.g. by installation of a water filter.

5.3.5 Influence of pressure testing and commissioning

Thorough flushing (preferably with an air/water flushing device) of the system immediately after the first filling will remove the solids, e.g. any debris or sand, which can have entered the pipework during installation and therefore decreases the likelihood of crevice corrosion under deposits.

5.3.6 Influence of operating conditions

5.3.6.1 Influence of temperature

The influence is similar to that discussed in 5.2.6.1.

5.3.6.2 Influence of flow conditions

An increased likelihood of crevice corrosion resulting from dirt and deposits as described in 5.3.1 to 5.3.5 is to be anticipated, especially under extended periods of stagnant water conditions (e.g. in tubes leading to taps that are used infrequently). The likelihood of corrosion is significantly smaller in flowing waters because of particle movement.

5.4 Stress corrosion

5.4.1 General

Stress corrosion is characterized by cracks produced as a result of the simultaneous influence of a specific corrosive agent and tensile stresses in the material that include residual stresses, construction stresses, operating stresses and thermal stresses. Generally, it does not occur in cold or moderately heated water systems.

In the systems under consideration that use austenitic stainless steels, cracks with transgranular path can start only at locations under attack from pitting corrosion, crevice corrosion or knife-line corrosion. Transgranular corrosion cracks can also be generated by fatigue stresses (corrosion fatigue).

5.4.2 Influence of the characteristics of the metallic material

The likelihood of transgranular stress corrosion cracking in austenitic stainless steels decreases as the nickel content increases. As stress corrosion cracking in the systems under consideration is induced by pitting or crevice corrosion, chromium, molybdenum and nitrogen are also beneficial. The likelihood of transgranular stress corrosion cracking in austentic-ferritic stainless steels is very small. Ferritic stainless steels are resistant to this type of corrosion.

Shot peening produces compressive stresses in the surface region and reduces any residual tensile stress, hence reducing the likelihood of stress corrosion cracking. However, if the shot peening material contains impurities of ferritic material, these will be embedded into the stainless steel surface, increasing the corrosion likelihood. In case of doubt, additional shot peening with fresh material is not helpful; the most suitable way to clean the stainless steel surface is by pickling.

5.4.3 Influence of the characteristics of the water

High chloride ion concentrations favour stress corrosion cracking. Hence, corrosion cracks caused by this type of corrosion in the waters in question can only start at locations that have been attacked by other types of corrosion (see 5.4.1) because such locations become enriched in chloride ions.

5.4.4 Influence of design and construction

Design and construction parameters that introduce tensile stress into the material influence the long-term behaviour of stainless steels with respect to stress corrosion.

During construction of a water system, tensile stresses can be induced in the components and cause stress corrosion cracking with the specific corrosive agents. Critical stresses can be minimized by, e.g. not overtightening threads and by constructing to appropriate recommendations.

When oxide films or scales are removed from weld seams by coarse grinding, increased hardness and residual tensile stresses occur in the surface region of the material and result in an increased likelihood of transgranular stress corrosion cracking of stainless steels. The surface material affected by grinding can be removed by pickling.

5.4.5 Influence of pressure testing and commissioning

Pressure testing and commissioning parameters are not known to influence the long-term behaviour of stainless steels with respect to stress corrosion.

5.4.6 Influence of operating conditions

5.4.6.1 Influence of temperature

Transgranular stress corrosion cracking as a consequence of pitting corrosion or crevice corrosion is not to be anticipated in austenitic stainless steels at wall temperatures below approximately 50 °C.

5.4.6.2 Influence of flow conditions

As pits are the initiation points for the occurrence of stress corrosion, 5.2.6.2 is analogously applicable.

5.5 Knife-line corrosion

5.5.1 General

The type of knife-line corrosion attack that occurs in the systems under consideration is characterized by a loss of the bond between stainless steel and certain silver based braze filler metals as a result of selective corrosion at the interface. This effect mainly occurs with joints brazed under oxidizing conditions using fluxes.

The incubation period for the occurrence of knife-line corrosion can be very long, even up to several years of service. In an advanced state, pitting corrosion can be initiated at the locations of knife-line corrosion.

5.5.2 Influence of the characteristics of the metallic material

The surface condition of the stainless steel does not influence the likelihood of knife-line corrosion.

Regarding on-site brazed joints with silver-based filler metal, the composition of the braze material can influence the rate of the knife-line attack, but at present there is no known composition which is able to totally resist this attack.

5.5.3 Influence of the characteristics of the water

The likelihood of knife-line corrosion of on-site brazed joints increases with increasing concentrations of chloride ions.

5.5.4 Influence of design and construction

Design and construction do not influence the likelihood of knife-line corrosion.

5.5.5 Influence of pressure testing and commissioning

Pressure testing and commissioning do not influence the likelihood of knife-line corrosion.

5.5.6 Influence of operating conditions

5.5.6.1 Influence of temperature

Temperature is not known to influence the occurrence of knife-line corrosion.

5.5.6.2 Influence of flow conditions

Flow conditions are not known to influence the occurrence of knife-line corrosion.

5.6 Corrosion fatigue

5.6.1 General

Corrosion fatigue is characterized by cracks produced as a result of the simultaneous influence of corrosion and cyclic stress.

5.6.2 Influence of the characteristics of the metallic material

Material composition is not known to influence the likelihood of corrosion fatigue. Ductility has an important influence as the corrosion likelihood increases with increasing ductility of isolated areas within areas of lower ductility.

A smooth surface is beneficial to reduce the likelihood of corrosion fatigue.

5.6.3 Influence of the characteristics of the water

The influence of the water composition on corrosion fatigue induced cracking is not very pronounced. In any case, it does not strongly depend, as do the other corrosion types discussed, on the concentration of chloride ions.

5.6.4 Influence of design and construction

In heated water systems cyclic stresses can occur because of thermal expansion and contraction. They can be avoided by proper design and construction.

Geometrical effects can influence corrosion fatigue properties.

5.6.5 Influence of pressure testing and commissioning

Pressure testing and commissioning parameters are not known to influence the long-term behaviour of stainless steels with respect to corrosion fatigue.

5.6.6 Influence of operating conditions

Besides the temperature variations mentioned in 5.6.4, no other parameters are known to influence the long-term behaviour of stainless steels with respect to corrosion fatigue.

6 Assessment of corrosion likelihood

In order to assess the corrosion likelihood of stainless steels in a water distribution and storage system, all the influencing factors, listed in EN 12502-1:2004, Table 1, and their possible interactions should be taken into consideration. This assessment should be carried out separately for all types of corrosion relevant to the specific corrosion system. Because of the complexity of the influencing factors and of their interaction, in most cases only a qualitative assessment is possible.

Bibliography

[1] EN 1011-3,*Welding — Recommendations for welding of metallic materials — Part 3: Arc welding of stainless steels*

[2] EN 10088-1:1995, *Stainless steels* — Part 1: *List of stainless steels*.

[3] EN 10088-2:1995, *Stainless steels* — Part 2: *Technical delivery conditions for sheet/plate and strip for general purposes*.

[4] EN 10088-3:1995, *Stainless steels* — Part 3: *Technical delivery conditions for semi-finished products, bars, rods and sections for general purposes*.

[5] EN 10312:2002, *Welded stainless steel tubes for the conveyance of aqueous liquids including water for human consumption — Technical delivery conditions.*

[6] EN ISO 3651-2:1998, *Determination of resistance to intergranular corrosion of stainless steels —Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid (ISO 3651-2:1998).*

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