euro inox
The European Stainless Steel Development Association

Safe use of stainless steel in swimming pool environments

Building Series, Volume 20

Euro Inox

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- national stainless steel development associations;
- development associations of the alloying element industries.

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ISBN 978-2-87997-394-4

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Safe use of stainless steel in swimming pool environments
First Edition 2013
(Building Series, Volume 20)

Publisher
Euro Inox
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1030 Brussels, Belgium
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Acknowledgements
Euro Inox wishes to thank Nigel Ward and Tony Newson, Nickel Institute, Brussels (B) and Alan Harrison, BSSA, Sheffield (UK) for their contributions and critical reading of the draft publication.

Cover photos
Wiegand-Mälzer, Starnberg (D) (right)
Baudin Châteauneuf, Châteauneuf sur Loire (F) (top left)

Contents

1 Introduction

Indoor swimming pools are among the most demanding built environments today, with high levels of temperature, humidity and corrosion load emanating from disinfection chemicals and their reaction products. Hence, the materials and finishes used should be suitable for the intended application and able to withstand these conditions while ensuring hygiene and preventing bacterial growth.

Stainless steels have been used successfully in swimming pools for decades. However, it should be borne in mind that over the years the swimming pool environments have changed significantly. Nowadays, swimming pools are not used solely for swimming but for leisure activities. Leisure pools have higher air temperatures with larger water surfaces than in previous decades. There is also an extended splash zone, which increases the general humidity around the swimming pools. People spend much more time in and around swimming pools and, as a result, there is a higher need for disinfectants. In addition to appropriate material selection and design solutions (e.g. avoidance of gaps), accessibility for cleaning and inspection is another important issue to be addressed. All these factors mean that the swimming pool environment has undergone significant change over the recent decades. Therefore, there was a need for a technical update in material selection.

Stainless steel lining is a proven option for the refurbishment of indoor swimming pools. Photo: Baudin Châteauneuf, Châteauneuf sur Loire (F)

The European Standard EN 13451-1:2011 provides clarification about the stainless steels eligible for swimming pool environments. Specifically, it makes a clear distinction between

- *load-bearing, safety critical components which are not regularly cleaned and exposed to indoor swimming pool atmospheres – one of the most corrosive environments to be found in the built environment, similar to that in road tunnels*
- *parts and equipment in indoor swimming pools, which are in the splash zone and/or which are regularly cleaned*
- *parts and equipment in outdoor swimming pools.*

Depending on where stainless steel is used, requirements can go from standard grade 1.4301 (304) to highly alloyed grades like 1.4529 with 20 % of chromium, 25 % of nickel and 6 % of molybdenum. The highly alloyed stainless steels are a must for instance in fasteners for suspended ceilings in indoor swimming pools, while for water features, accessories and the cladding of the pool itself standard grades are proven options. The present publication summarizes which type of stainless steel should be considered for the respective types of environments in accordance with current European standardisation.

The European standard EN 13451-1:2011 Swimming pool equipment – Part 1: General safety requirements and test methods addresses the use of stainless steel for load-bearing applications in swimming pool atmosphere in normative Annex G [1]. The standard reflects the current knowledge at the time of its development. However, some additional stainless steel grades might be used in future technical developments.

This publication is intended as a reminder to architects, designers, material specifiers, facility owners and persons responsible for the maintenance of swimming pools. It is of vital importance to distinguish between outdoor and indoor swimming pools as well as structural and non-structural applications, especially where failure in structural applications might cause harm or damage. This latter category may encompass items not normally considered as ‘structural’ (e.g. advertising signs, support brackets, loud speakers, lamps, etc.) [2].

2 Swimming pool environments

Materials selection for safety-relevant components in indoor swimming pools is primarily a matter of corrosion resistance and the possibility to inspect the components. The term stainless steel often gives rise to the assumption that these steels are not subject to corrosion. However, even if the resistance of stainless steel to corrosion is high, it does not imply immunity from corrosion. There are more than 120 commercially available stainless steel grades with markedly different levels of corrosion resistance. Contrary to common belief, the most adverse corrosion conditions are not found in direct contact with swimming pool water but in the atmosphere above the pool, specifically behind suspended ceilings [3] or even in quite distant locations.

Higher air temperatures, larger water surfaces and extended splash zones are characteristic of swimming pools today. Photo: Roigk, Gevelsberg (D)

Typical conditions found in indoor swimming pools are [4]:

- air temperature usually 0–4 °C higher than pool water temperature;
- relative humidity between 40 % and 80 %, ideally under 60 %
- air speed in proximity of users <0.10 m/s.

The atmosphere of indoor swimming pools is often characterised by a relatively high content of chlorine and chlorine compounds (mainly from chlorinated swimming pool water) at a relative humidity of approximately 60–70 %. This gives rise to a specific "swimming pool odour". These substances may be transported both as gases and as aerosols. In addition to sodium chloride, relatively large quantities of calcium and magnesium chloride have also been detected in many cases. Chloride contents of 2–5 % and pH values of 3–4 are typical [3]. The relative humidity is influenced by changes in daytime temperature and swimming activity, while switching off the air-conditioning system overnight may favour the formation of deposits. In many cases, this factor should also be taken into account.

The atmospheric conditions found in outdoor swimming pools are relatively mild.
Photo: Wiegand-Mälzer, Starnberg (D)

If evaporation occurs in chloride-containing media, the chloride concentration at contact surfaces rises and hence the likelihood of corrosion is significantly increased. The serious consequences of high corrosion loads in swimming pool atmospheres, with regard to the safety of structures, became clear only after the collapse of the concrete ceiling of an indoor swimming pool in Uster, Switzerland, in 1985. Stress corrosion cracking of the suspension rods made of stainless steel, grade 1.4301 (304) caused the failure. Until this incident occurred, the risk of stress corrosion cracking of this grade of steel was considered to occur at higher temperatures than those found in swimming pool atmospheres.

It can be concluded that, over recent decades, the swimming pool environment has become more aggressive. Measurements made [5] on the corrosion rate of zinc indicate that, in general, swimming pool atmospheres are classified as corrosivity class C4. However, swimming pool environments can in some cases be classified as C2 and, in other cases, the corrosion rate of zinc can also exceed the limits of C5 (30–60 g/m^2 year) [6], which is the highest class described in EN ISO 12944-2:1998 Part 2 [7]. The guidance in the standard is informative only and, as the corrosivity classes are defined with other metallic materials in mind, it may not predict the performance of stainless steels.

3 Stress corrosion cracking in swimming pool environments

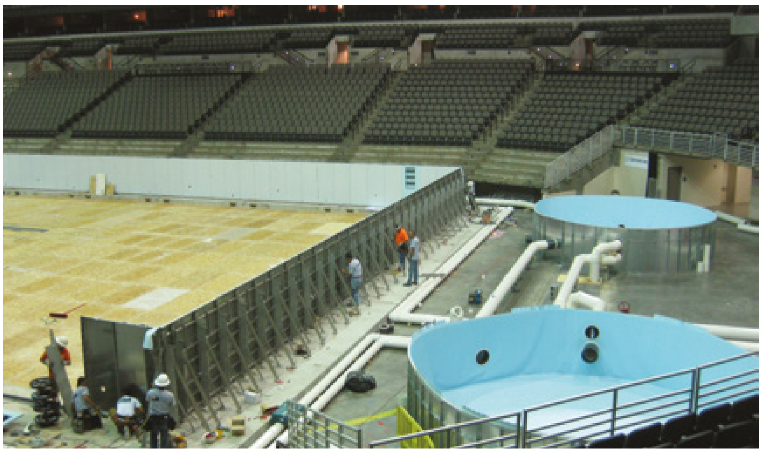
Stress corrosion cracking (SCC) phenomena do not normally present a problem for structural engineers working with carbon steels. As a failure mechanism, it is outside the experience of most engineers and, therefore, the chance that risk factors may be overlooked is high [8]. SCC may occur under a specific combination of the following three pre-conditions:

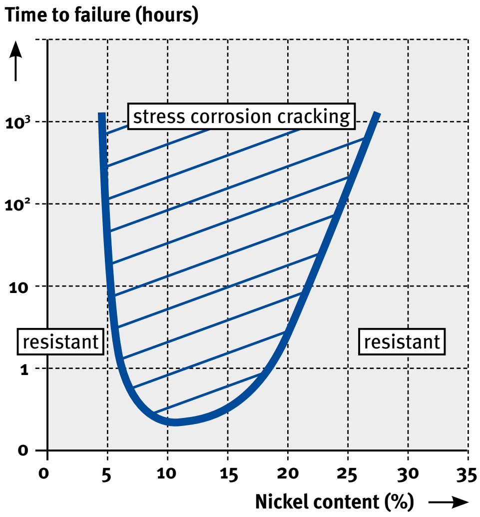
- high stress levels in the component (arising from applied load or from residual stresses from welding or forming of components)
- susceptibility of the particular grades of steel
- specific aggressiveness of the environment

Until the 1980s, it was believed that stress corrosion cracking could not occur at temperatures below 50 °C. After an accident in a Swiss pool, intensive research was carried out to find the cause of the problem and to identify potential solutions. The investigation determined that failure was due to chloramines, which are formed from the chlorine used for disinfection of the pool and human fluids (e.g. sweat and urine). The chloramines evaporate and concentrate on the metal surfaces. As some areas are difficult, or even impossible, to clean (e.g. the rods used in suspended ceilings), the accumulation of chloramines can lead to high concentrations even in areas quite remote from the pool. With temperatures in the range of 26–32 °C, the conditions are sufficient to initiate stress corrosion cracking. As a result, inspections of load-bearing components were undertaken and, since then, amended guidelines for safe material selection have been published at national level [9, 10].

With stress corrosion cracking, there is very little visible evidence of corrosion attack on the surface. The metal or alloy appears virtually unattacked over most of its surface, while fine cracks progress through its cross-section. Cracks may propagate quite rapidly and complete failure of the structure can occur without previous warning. Therefore, it is important to select stainless steel grades suitable for applications in chloride environments. It should be specifically noted that stress corrosion cracking relates only to components in the pool atmosphere and not those fully immersed in the pool water [2].

Stainless steel solutions are also available for temporary pool structures. Photo: A&T Europe, Castiglione / Centro Inox, Milan (I)





With regard to stainless steels, stress corrosion cracking only occurs in austenitic grades and is related to their nickel content. Steel grades with a nickel content in the range between 7 % and 15 % are all susceptible to stress corrosion cracking, while austenitic stainless steel grades with high nickel and molybdenum contents are much more resistant to this kind of corrosion.

Duplex stainless steels are resistant to stress corrosion cracking. However, selective corrosion of the ferritic phase was observed for duplex grades resulting in superficial attacks in swimming pool environments. These materials are therefore not recommended for use in load bearing applications in indoor swimming pool atmospheres [1, 5, 11, 12].

Ferritic grades do not generally suffer from stress corrosion cracking, but their general corrosion resistance is not sufficiently high for such applications [13].

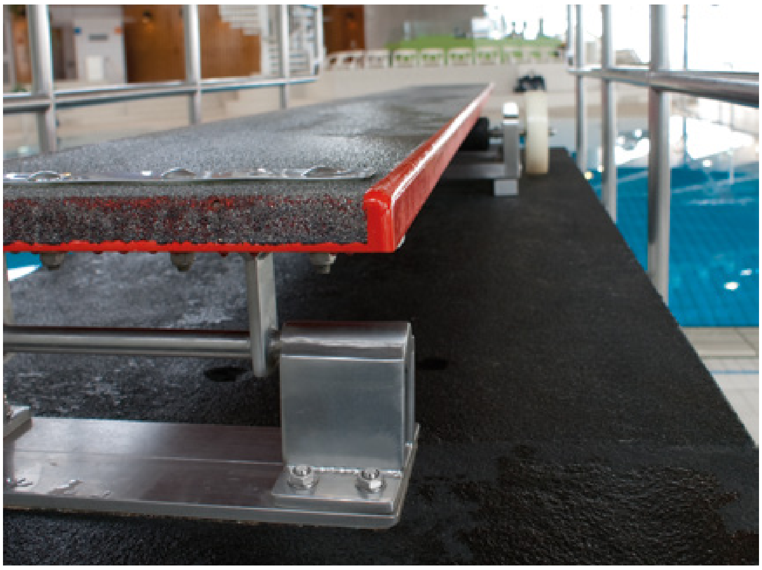
Structural engineers and pool operators are advised to take some practical measures to prevent stress corrosion cracking which have proven useful over many years.

Table 1. Measures to prevent stress corrosion cracking (SCC) and minimise its consequences [14]

By the structural engineer	By the pool operator
Careful consideration of the corrosion risks and potential for SCC during the design and fabrication of the swimming pool building and components	Carefully maintaining the chemical balance of the pool water by regular monitoring and dosing
Design to avoid corrosion and facilitate inspection and maintenance	Ensuring that the bathing load of the pool is not exceeded and that the potential for organic contamination is minimised by the provision of good pre-shower facilities, toilets and instruction to bathers
Careful selection of appropriate stainless steel grades	Maintaining air quality by the correct operation of ventilation and heating plants (switching off the air-conditioning system overnight may favour the formation of very corrosive deposits)
Adoption of correct fabrication procedures including removal of weld heat tint	Regular cleaning to remove dirt and contamination
	Regular inspection of safety-critical[1] components for signs of corrosion and SCC

[1] Note: Failure of a safety-critical component may cause personal injury.

4 Indoor swimming pools disinfected with chlorine



Evaporation, condensation and drying generate a highly corrosive environment in indoor swimming pools. Photo: Fischer, Waldachtal (D)

Temperature fluctuations in indoor swimming pools that, result in cycles of evaporation, condensation and drying, generate a highly corrosive environment due to the accumulation of various chloride-bearing compounds in the atmosphere. Therefore, it is important to make a clear distinction between those structural parts, items of equipment, fixtures and fittings that can, and those that for whatever reason cannot, be cleaned regularly.

4.1 Components not regularly cleaned

As structural parts in swimming pool environments may be subjected to stress corrosion cracking, an informed decision should be made when material selection is undertaken. For all structural parts not subject to regular cleaning and solely made of stainless steel, the following materials are suitable according to EN 13451-1 [15]:

- 1.4565 (X2CrNiMnMoNb25-18-5-4)
- 1.4529 (X1NiCrMoCuN25-20-7)
- 1.4547 (X1CrNiMoCuN20-18-7)

In environments where the swimming pool water has a chloride concentration of less than 250 mg/l (which is the upper limit in drinking water), grade 1.4539 (904L) could be used in addition to the stainless steel mentioned above.

The steel grades suitable for structural parts (i.e. components with load-bearing functions), where regular cleaning is not possible, are highly alloyed with chromium, nickel and molybdenum. These alloys are resistant to stress corrosion cracking.

Table 2. Stainless steel grades suitable for the components and parts in swimming pool environment not subject to regular cleaning

Steel designation		Approx. AISI/ ASTM	C	Cr	Ni	Mo	N	Others
Name	*Nr.*		*% by mass*					
X2CrNiMnMoNb25-18-5-4	1.4565	-	≤0.030	24.0–26.0	16.0–19.0	4.0–5.0	0.30–0.60	Mn 5.0–7.0
X1NiCrMoCuN25-20-7	1.4529	-	≤0.020	19.0–21.0	24.0–26.0	6.0–7.0	0.35–0.50	Cu 0.5–1.5
X1CrNiMoCuN20-18-7	1.4547	-	≤0.020	19.5–20.5	17.5–18.5	6.0–7.0	0.18–0.25	Cu 0.5–1.0
X1NiCrMoCu25-20-5*	1.4539*	904L	≤0.020	19.0–21.0	24.0–26.0	4.0–5.0	≤0.15	Cu 1.2–2.0

* Suitable only for the environments where water has a chloride concentration of less than 250 mg/l

For structural parts not subjected to regular cleaning, high-alloyed stainless steel are required. Photo: Roigk, Gevelsberg, (D)

Safety critical elements with load bearing functions (e.g. suspended ceilings, wall and ceiling panels, signage, light fittings, air conditioning ducts, etc.) should be identified at the design stage and the safety risks given specific consideration. The selected fixing should be safeguarded by clear allocation of responsibility for [16]:

- selection and design by competent persons
- supervision of installation by trained personnel
- proof testing of installed fixings where appropriate

4.2 Components that are regularly cleaned

Where the parts and components of swimming pool equipment are easily accessible and subject to regular cleaning, the following stainless steel grades, in addition to those listed in Table 2, are suitable:

- 1.4401 (X5CrNiMo17-12-2)
- 1.4404 (X2CrNiMo17-12-2)
- 1.4578 (X3CrNiCuMo17-11-3-2)
- 1.4571 (X6CrNiMoTi17-12-2)
- 1.4439 (X2CrNiMoN17-13-5)
- 1.4462 (X2CrNiMoN22-5-3)

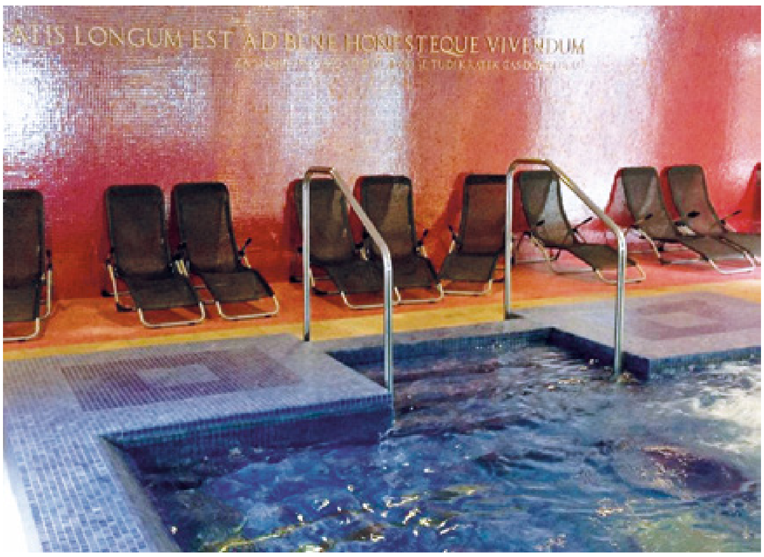
Only stainless steels like 1.4529 can be used for safety critical applications in swimming pools. Photo: Hilti Austria, Vienna (A)

Cleanability makes stainless steel a preferred choice for swimming pool accessories. Photos: E.S.M., Pirna (D) (left), Roigk, Gevelsberg (D) (right)

Table 3. Stainless steel grades suitable for the components and parts in swimming pool environment subject to regular cleaning

Steel designation		Approx. AISI/ ASTM	C	Cr	Ni	Mo	Others
Name	*Number*		*% by mass*				
X5CrNiMo17-12-2	1.4401	316	≤0.070	16.5–18.5	10.0–13.0	2.0–2.5	-
X2CrNiMo17-12-2	1.4404	316L	≤0.030	16.5–18.5	10.0–13.0	2.0–2.5	-
X3CrNiCuMo17-11-3-2	1.4578	-	≤0.040	16.5–17.5	10.0–11.0	2.0–2.5	Cu 3.0–3.5
X6CrNiMoTi17-12-2	1.4571	316Ti	≤0.080	16.5–18.5	10.5–13.5	2.0–2.5	Ti: 5xC to 0.70
X2CrNiMoN17-13-5	1.4439	317LMN	≤0.030	16.5–18.5	12.5–14.5	4.0–5.0	N 0.12–0.22
X2CrNiMoN22-5-3	1.4462	2205	≤0.030	21.0–23.0	4.5–6.5	2.5–3.5	N 0.10–0.22

With regular cleaning, the accumulation of chloride-bearing compounds is minimised.



Regular cleaning minimises the accumulation of chloride-bearing compounds on the surfaces of pool equipment (e.g. pool ladders, safety rails, doors and windows, benches, etc.). While EN 13451-1 requires swimming pools to have documented inspection and cleaning procedures, the standard does not specify clear, appropriate duties in this area for all potentially vulnerable structures [17].

5 Outdoor swimming pools disinfected with chlorine

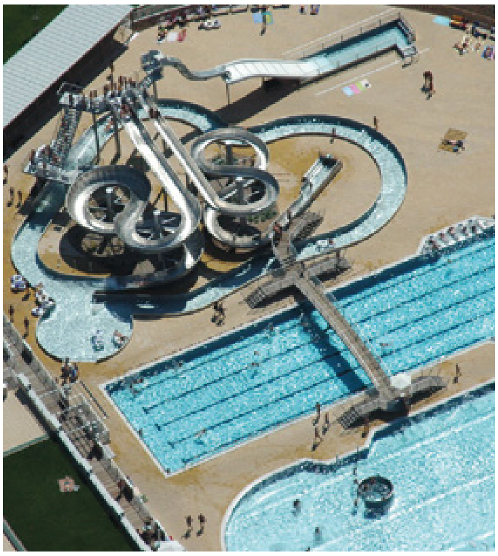
Outdoor swimming pools are also disinfected with chlorine. However, the atmospheric conditions are much less corrosive than in indoor swimming pools, because rainfall naturally cleans the stainless steel surfaces and washes the chloride-bearing compounds away. Nevertheless, local higher corrosion loads can occur on above water surfaces and these areas may require specific cleaning procedures. As the environment is less corrosive than that in indoor swimming pools, stainless steel grades that exhibit more moderate corrosion resistantce can be used:

- 1.4301 (X5CrNi18-10)
- 1.4307 (X2CrNi18-9)
- 1.4567 (X3CrNiCu18-9-4)
- 1.4541 (X6CrNiTi18-10)
- 1.4318 (X2CrNiN18-7)

Table 4. Stainless steel grades suitable for the components and parts in outdoor swimming pools

Steel designation		Approx. AISI/ ASTM	C	Cr	Ni	Mo	Others
Name	*Number*		*% by mass*				
X5CrNi18-10	1.4301	304	≤0.070	17.5–19.5	8.0–10.5	-	-
X2CrNi18-9	1.4307	304L	≤0.030	17.5–19.5	8.0–10.5	-	-
X3CrNiCu18-9-4	1.4567	-	≤0.040	17.0–19.0	8.5–10.5	-	Cu 3.0–4.0
X6CrNiTi18-10	1.4541	321	≤0.080	17.0–19.0	9.0–12.0	-	Ti: 5xC to 0.70
X2CrNiN18-7	1.4318	301LN	≤0.030	16.5–18.5	6.0–8.0	-	-

Stainless steel surfaces are unaffected by ultraviolet light.
Photos: Wiegand-Mälzer, Starnberg (D)



6 Alteration of existing equipment

When alteration of existing swimming pool parts and equipment is under consideration, the above-mentioned material selection rules (see sections 4 and 5) should be followed.

Furthermore, it should be specifically noted that the painting of stainless steel surfaces does not provide additional protection against corrosion. Paint can spall off and form crevices which are prone to corrosion. Organic coating cannot justify the selection of a lower alloyed grade.

In outdoor swimming pools, standards grades like 1.4404 are commonly used.
Photo: Wiegand-Mälzer, Starnberg (D)

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ISBN 978-2-87997-394-4

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