Successful Stainless Swimming Pool Design

by Catherine Houska, CSI and James Fritz, Ph.D
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Metals have been used in natatorium applications for over 40 years, but there are distinct differences in long-term performance. Knowledgeable stainless steel selection and maintenance produces outstanding service performance and experience has demonstrated that no metal can match its performance in pool-level natatorium applications. Even if superficial corrosion staining occurs, it does not adversely affect the structural integrity of stainless steel applications immediately around the deck or within the swimming pool and the staining is easily removed.

Figure 1

Photo Courtesy of Nickel Institute

Stainless steel can provide an outstanding combination of aesthetic appeal, corrosion resistance, strength, durability, and cleanability, and they are commonly used for a wide range of indoor and outdoor pool applications, including ladders, handrails, diving platforms, slide assemblies, gutters, and ventilation systems. These components are frequently still structurally sound and aesthetically pleasing after more than 25 years of service.

Figures 1, 2 and 3: Stainless steel swimming pool slide and water feature.

Figure 2

Photo Courtesy of Nickel Institute

Figure 3

Photo Courtesy of Martina Helzel

However, this does not mean stainless steel is without its potential problems – since the 1970s, the trend in recreational swimming pools has been toward higher water temperatures, increased numbers of bathers and water features (e.g. slides and fountains), and higher levels of chemical disinfectants. Additionally, higher energy costs have caused some pool operators to reduce their air replacement rates.

These factors increase chlorination and atmospheric moisture, making pool environments much more corrosive for all materials. These more aggressive conditions necessitate more corrosion-resistant alloys and greater maintenance if an attractive appearance is to be maintained. Increasing specifiers and pool managers understanding of stainless steel selection and maintenance is a critical aspect of achieving corrosion-free performance.

Other less corrosion resistant metals are sometimes used in swimming pool applications. The relative installed cost of aluminum is lower and the corrosion of aluminum components is often overlooked because its corrosion product is white to whitish-gray in appearance. The significantly higher corrosion rate of aluminum in chloride-containing environments makes inspection important so that metal corrosion loss and structural integrity can be determined. Relatively low cost painted and plated carbon steel are sometimes used for pool applications, but their performance is dependent on coating quality and maintenance. Once the protective coating or plating starts to fail, there can be rapid corrosion and structural deterioration of the carbon steel making careful regular inspection and recoating necessary.

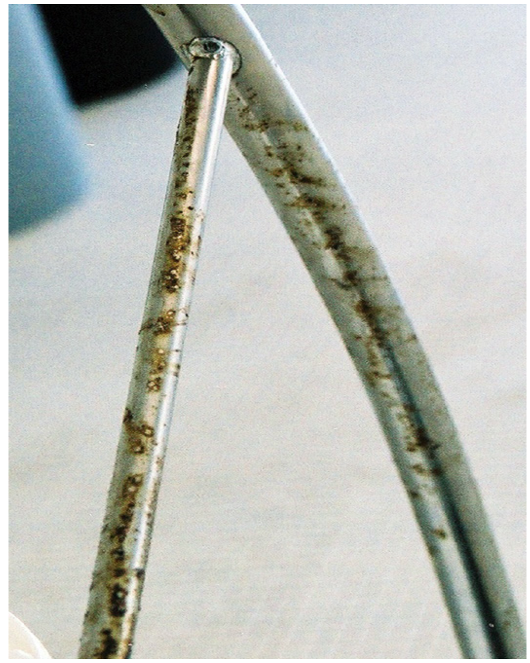

Figure 4: This chrome plated carbon steel reel for holding lane markers has only been in use for a few years but there has already been substantial corrosion under the plating. Photo Courtesy of TMR Consulting.

Figure 5: Carbon steel brushes were used by a cleaning contractor on this stainless steel door hinge that was installed beside an indoor swimming pool. The areas with carbon steel contamination are rusting. Photo courtesy of TMR Consulting

The Causes of Corrosion

The chlorine-based chemicals used to disinfect pool water produce chloramines due to a reaction with nitrogen-bearing compounds such as urea (from sweat and urine). Chloramines are very volatile and are passed into the atmosphere where they can be deposited on metal surfaces, decomposing in the condensate to form a corrosive solution. Repeated cycles of condensation followed by evaporation cause accumulation of these aggressive chloride-bearing compounds on above-water surfaces. These compounds are responsible for most of the metal corrosion problems found around swimming pools.

Corrosion of stainless steel in swimming pool projects is usually caused by one of the following factors (or a combination thereof):

- inappropriate stainless steel or finish selection;
- inadequate or improper maintenance;
- poor fabrication techniques; and
- deficient control of the pool environment.

The aggressiveness of an indoor pool environment varies substantially with temperature, relative humidity (RH), number of bathers, and the air replacement rate.

Tables 1 and 2 summarize the various stainless steel candidates for natatorium applications and their general characteristics. Immersed surfaces and areas routinely splashed by pool water are far less prone to corrosion. Similarly, outdoor pool environments, where there is ample fresh air and periodic rain-washing, are not as corrosive as their indoor counterparts. On the other hand, the ceiling and other isolated areas in indoor swimming pool environments are the areas that are most prone to corrosion because they are not splashed and cleaning is less likely, allowing significant accumulation of chloride-containing compounds.

Table 1: General Characteristics of Stainless Steels Used In Swimming Pool Applications

Stainless Steel Designation (UNS number)		General Characteristics
Standard Cr - Ni austenitic stainless	304 (S30400) 304L (S30403)	• Good corrosion resistance • Excellent formability, weldability, and impact strength • Readily available • Susceptible to SCC in pool buildings *
Standard Cr - Ni- Mo austenitic stainless	316 (S31600) 316L (S31603)	• Better corrosion resistance than 304/304L • Excellent formability, weldability, and impact strength • Readily available • Susceptible to SCC in pool buildings *
Higher alloyed austenitic stainless	317LMN (S31726) 904L (N08904)	• Better corrosion resistance than 316/316L • Good ductility, weldability, and impact strength • Good resistance to SCC in pool buildings
6%-Mo super austenitic stainless	254 SMO® (S31254) AL-6XN® (N08367) 25-6MO (N08925)	• Exceptional corrosion resistance • Good formability, weldability, and impact strength • Good resistance to SCC in pool buildings
Duplex stainless	2205 (S33305)	• Corrosion resistance similar to 904L and 317LMN • High Strength • Good weldability, and impact strength • Good resistance to SCC in pool buildings
Super duplex stainless	SAF 2507® (S32750)	• Similar corrosion resistance to 6%-Mo stainless steels • High strength • Weldable • Good resistance to SCC in pool buildings

Notes: 254 SMO is a registered trademark of Outokumpu. AL-6XN is a registered trademark of ATI Properties Inc. SAF 2507 is a registered trademark of Sandvik AB.
A high quality, smooth stainless steel finish is assumed for all of the applications above. SCC is the abbreviation for stress corrosion cracking.
* This only applies if load bearing, cold worked components, such as ceiling structural supports, are not regularly washed or splashed.

Types 304 and 316 stainless steels are often used for swimming pool applications that are immersed or regularly splashed with pool water. Type 304 can provide good performance in cooler-temperature pools with lower chlorination levels and careful environmental control. Painted or coated Type 304 is sometimes used for more aggressive applications such as ductwork, while bare Type 316 is preferred for higher-temperature pools or spas with increased chlorination levels, as well as in applications where there is less careful chlorination control.

Highly stressed stainless steel applications inside pool buildings can be susceptible to stress corrosion cracking (SCC) and possible catastrophic failure.[1] Susceptible stainless steels include 304/304L, 316/316L, 201/201L, and 321 or any other austenitic stainless steel with a nickel (Ni) content in the eight to 10 percent range. Load-bearing or highly cold-worked components are at greatest risk. This problem is most likely to affect components near the ceiling where there is a high probability of accumulating significant chloramine deposits on metal surfaces. In other words, stainless steel surfaces that are fully immersed, frequently splashed with pool water, or regularly cleaned are rarely at risk of SCC.

Table 2: Suggested Stainless Steels For Various Swimming Pool Locations

Location	Description	Stainless Steel
Immersed	1-3 ppm chlorine, lower temperature pool, excellent water chemistry control with limited or no shocking	Type 304
Immersed	1-3 ppm chlorine, lower temperature pool with potentially poor water chemistry control	Type 316 *
Immersed	3-5 ppm chlorine, higher temperature pool or spa, excellent water chemistry control with limited or no shocking	Type 316
Immersed	3-5 ppm chlorine, higher water temperature pool or spa, potentially poor water chemistry control	Type 316 *
Splashed Not load bearing	Regular maintenance cleaning, excellent water chemistry control, air replacement rates, and humidity control	Type 304
Splashed Not load bearing	Regular maintenance cleaning, unknown water and air quality control	Type 316
Indoors Splashed Not load bearing	Minimal maintenance, regular shocking, low air replacement rates, and/or poor quality finish	317LMN, 904L, 2205
Indoors Not splashed Not load bearing	Periodic maintenance cleaning, good quality finish, excellent air replacement rates and humidity control	Type 316
Indoors Not splashed Not load bearing	Minimal or no maintenance cleaning, poor quality finish, poor air replacement rates, and/or poor humidity control	317LMN, 904L, 2205
Indoors Not splashed Load bearing	Regular maintenance cleaning, good quality finish, excellent air replacement rates and humidity control	317LMN, 904L, 2205
Indoors Not splashed Load bearing	Minimal or no maintenance cleaning, poor quality finish, poor air replacement rates, and/or poor humidity control	254 SMO®, AL-6XN®, 25-6MO

Notes:
* If there is regular shocking and the chlorine is not rapidly and evenly distributed throughout the water, there may be pitting of type 316 in areas with extremely high chlorine concentrations. This may also occur if the chlorine levels are not monitored and regularly, significantly exceed 5 ppm. A more corrosion resistant stainless steel could be specified but the more effective solution is better water management.

The outstanding corrosion resistance and good SCC resistance of the six-percent-molybdenum (Mo) stainless steels make them ideal candidates for critical above-water applications that are neither splashed nor cleaned. Although not as readily available, the super duplex stainless steels provide similar corrosion-resistance and are also good choices. 904L, 317LMN, and 2205 duplex stainless steel offer better resistance to staining and SCC than Types 304 or 316 stainless steel. Appropriate selection of a SCC resistant stainless steel should provide worry and maintenance-free performance of structural components over the life of the pool. These more highly alloyed SCC resistant stainless steels are usually more expensive than Types 304 and 316 but the duplex stainless steels provide much higher strength. If a structural engineer takes full advantage of duplex stainless steel's strength and decreases section sizes, their installed cost can be similar to that of Type 316. Existing safety-critical and load-bearing applications fabricated from SCC susceptible alloys such as Types 304 or 316 stainless steel require periodic cleaning and inspection to ensure long-term structural integrity.

Finish specification can influence stainless steel performance. When good and poor quality stainless steel finishes are placed side-by-side under equivalent conditions, the latter is much more likely to exhibit corrosion staining. Very smooth finishes (e.g. a dull mill finish on ductwork or a mirror-like finish on a polished railing) generally provide the best corrosion performance. When a brushed or satin No. 4 finish is desired, it should be applied with silicon carbide abrasives that are replaced as soon as they begin to wear. Aluminum oxide and non-metallic abrasive pads can smear the finish and create micro-crevices where corrosion can initiate.

Figure 6: This weld within a swimming pool gutter was not cleaned properly and pitting corrosion is occurring along the weld seam. Photo courtesy of TMR Consulting

Muriatic acid (hydrochloric acid) should not be used to clean concrete or tile near stainless steel as it can cause rapid corrosion. Should hydrochloric acid come in contact with stainless steel, it must be washed off immediately and neutralized. Cleaning products containing even small amounts of hydrochloric acid should also be avoided.

Poor maintenance and the use of inappropriate cleaning compounds can be another factor in corrosion performance. Carbon steel wool and wire brushes should never be used for cleaning or 'refinishing' stainless steel since particles can become embedded in the surface. These carbon steel particles corrode at the same rate as unprotected carbon steel and cause unsightly surface damage.

In cases where stainless steel components have welded joints, the welds should provide the same level of corrosion performance as the surrounding metal. Therefore, corrosion on and around welded stainless steel joints is unacceptable. Grinding and pickling joints is the best means of restoring a weld's corrosion resistance.

Immersed Applications

Stainless steel's corrosion resistance makes it an ideal material for components completely or partially immersed in chlorinated water, including pool gutters, ladders, underwater light fixtures, liners, and water piping. When selecting metals for these applications, pool water temperature, chlorination level, and the likelihood of careful water chemistry management should be considered.

The preferred free chlorine range in swimming pools is 1 to 3 ppm. (In spas and higher temperature pools, it is 3 to 5 ppm.) Superchlorination and 'shocking' (i.e. a maintenance practice that uses oxidization to break down water-soluble bather waste) temporarily increases pool chlorine levels to levels as high as 10 ppm and can accelerate corrosion of pool materials. High levels of chlorination can be minimized or eliminated through careful water management.

Various aluminum (e.g. 1100, 3003, and 6061), cast iron, carbon steel, and stainless steel alloys were exposed to 3- and to 5-ppm chlorinated water for 250 days and to 20- to 25-ppm chlorinated water for 32 days. Aluminum had low corrosion rates up to 2 ppm of chloride, but, above this level, corrosion increased with rising chloride levels. The relatively linear, rapid increase in aluminum, carbon steel, and cast iron corrosion rates with increasing chlorination levels is shown in Figure 6. The stainless steels (Types 304, 316) that were tested had insignificant general corrosion rates (<0.1 mpy) at all chlorination levels and are therefore not shown on the graph. Even during the 32-day exposure at 20 to 25 ppm chlorine, there was no general or pitting corrosion of either Type 304 or 316 stainless steel.[2]

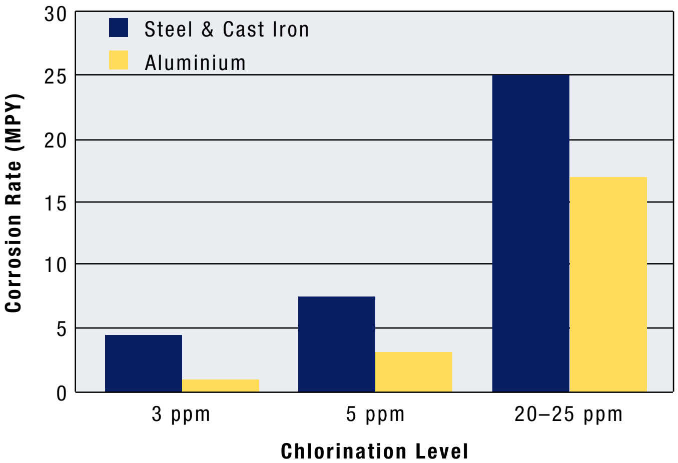

Figure 7: Carbon steel, cast iron, aluminum and stainless steel alloys were tested at three different chlorination levels and the average rate of metal loss determined in mils per year (mpy). The general corrosion rate of type 304 and 316 stainless steel was so low (<0.1 mpy) at all chlorination levels that it could not be graphed.

When designing with any metal in a pool environment, crevices should be avoided or sealed since they can be sites for accelerated corrosion. Care should also be taken to prevent direct contact between different metals to prevent galvanic corrosion.

Type 304 stainless steel is most suitable for immersed or partially immersed applications in lower temperature pools with closely monitored pool chemistry. Type 316 stainless steel is a more conservative choice because it provides greater corrosion resistance and is preferred for pools with up to 5-ppm chloride. If the water handling system does not rapidly distribute the chlorine, pool shocking can produce temporary, localized, very high chloride concentrations. Repeated excessive chlorination without proper monitoring can also cause very high chlorine levels. Although stainless steel is more resistant to chlorine than other metals, pitting corrosion can occur at very high chlorination levels and pool water chemistry should be carefully monitored.

Pool Liners

Stainless steel swimming pool liners have long been in use in Europe and Japan for both new construction and pool refurbishment and are starting to be used in North America. Stainless steel's popularity is the result of the material's long life, low maintenance costs, and hygienic benefits. The ability to effectively remove bacteria and contaminates has made stainless steel the material of choice for commercial kitchens, food and medicine manufacturing, water treatment and other applications where surface cleanability is critical.[3, 4, 5] In Japan, stainless steel swimming pool liners are popular because of their documented ability to withstand earthquake damage under conditions where traditional concrete and fiber-reinforced polymer (FRP) pool linings have failed.[6]

Although the initial cost of repairing existing concrete or applying vinyl and fiberglass liners is lower, they are short-term solutions that require more frequent maintenance to remove algae and make repairs. They have shorter service lives than stainless steel liners. The oldest known European stainless steel swimming pool liner has provided more than 40 years of service with no sign of deterioration. Algae is usually not a problem in pools with stainless steel walls, because the plants do not adhere to the relatively smooth surface. The smooth walls also eliminate concern about abrasion of swimmer's skin.

Two installation approaches are being used for stainless steel pool liners. The first employs Type 304 panels coated with polyvinyl chloride (PVC). The panels are bolted together and held in place with horizontal and vertical stainless steel bracing. Solvent 'welding' the PVC produces a smooth, watertight joint seal. The pool markings can then be painted directly on the PVC. While stainless steel has lower crevice corrosion rates than other liner substrates, prompt repair is still encouraged should there be any damage.[7]

Figure 8: This swimming pool in Munich, Germany was relined with Type 316 stainless steel panels that were welded together. Photo courtesy of Martina Helzel

Bare Type 316 stainless steel has been used for pool linings, particularly in Europe.[8] In relining applications, stainless steel has replaced plastic and ceramic tiles, while in new pools, self-supporting structures composed of stainless steel sheet and structural framing are typically used for water depths up to about 2 m (6.5 ft). Deeper pools typically require a secondary support structure or heavier wall panels due to water pressure loads. The stainless steel panels are welded together, producing a watertight structure, and the seams are pickled to restore corrosion resistance. Pool lane markings can be applied in advance using electrochemical coloring, which eliminates maintenance painting.

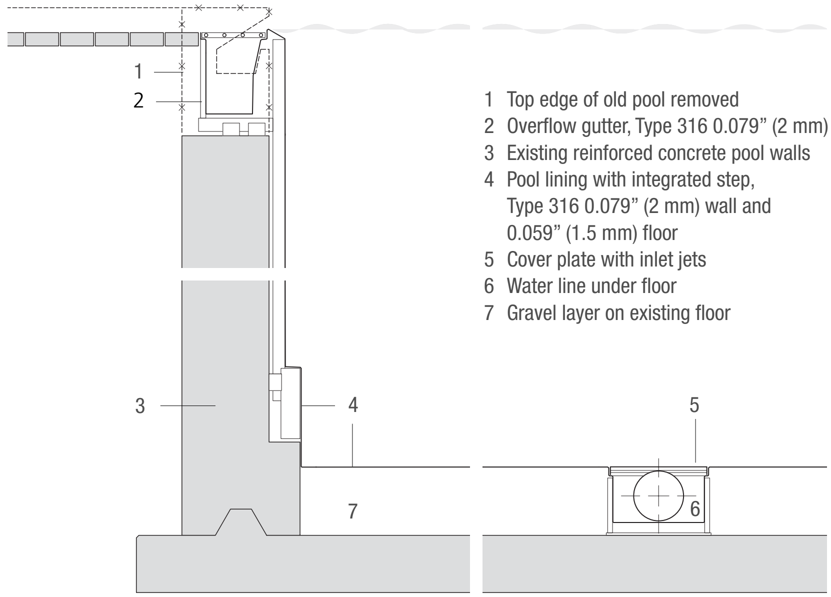

Figure 9: The relining process is shown in this illustration. Courtesy of EuroInox.

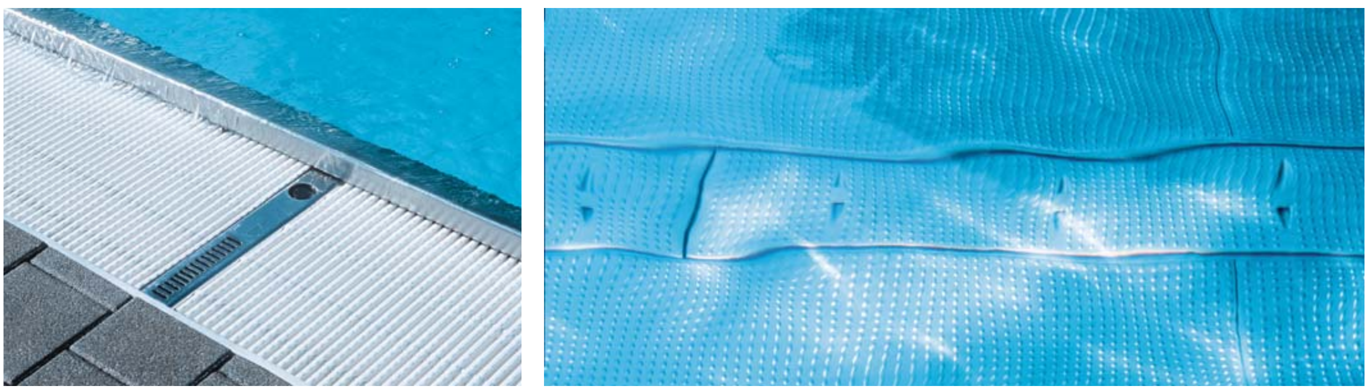

Figure 10 and 11: Type 316 pool gutters and water jet openings in the floor plates. Photos courtesy of Martina Helzel

Above Pool Level

Due to the increased likelihood of chloramine accumulation, above-water locations are the most corrosive areas around a swimming pool. When these areas are splashed or cleaned regularly, corrosion problems are much less likely (e.g. pool deck level and some locker rooms applications). However, above-water applications in indoor natatoriums that are not splashed are the most corrosive in the pool environment because they do not benefit from indirect cleaning caused by the water. This category includes elevated balconies, ductwork, and ceiling components, but some deck-level applications may also fall into this category.

Components that are neither structural nor splashed/cleaned (e.g. decorative panels and ventilation ducts) should be fabricated from materials at least as corrosion-resistant as Type 316 stainless steel and a high-quality smooth finish should be used. It is difficult to clean and inspect elevated locations, so more corrosion-resistant stainless steels are generally preferred.

Figure 12: Corrosion of a Type 304 stainless steel roof deck above an indoor swimming pool.
Photo courtesy TMR Consulting

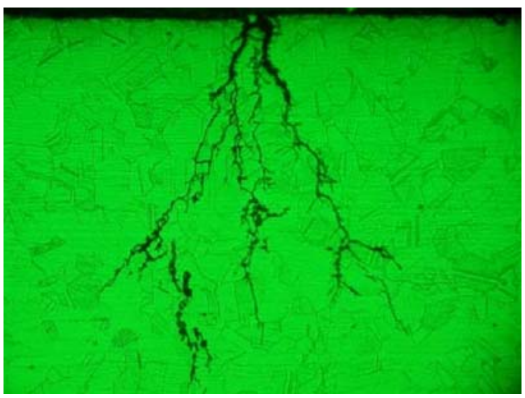

Figure 13: This magnified cross-section of a sample from the roof deck illustrates the extensive SCC that occurred.
Photo courtesy of TMR Consulting

SCC is a concern in load-bearing applications that are not splashed with pool water or cleaned, such as ceiling hangers, fasteners, brackets, supports, bolts, wires, cables, and hooks. Figures 12 and 13 depict an example of SCC attack. This North American Type 304 stainless steel natatorium roof deck was never inspected or cleaned. After a decade of exposure, there was significant brown staining on the roof panels above the diving platforms. Samples were removed from the roof deck and close examination revealed shallow pitting and extensive cracking with some fissures penetrating 80 percent of the cross-section. This cracking resulted because of the following factors:

- The stainless steel was susceptible to SCC.
- There were relatively high residual stresses from the cold working the roof panels and high roof service stress loads, particularly with winter snow loads.
- There was no cleaning to remove the accumulation of aggressive chloride compounds.
- It was a poorly controlled pool environment.

Stress corrosion cracking can lead to a severe loss of structural integrity and possibly catastrophic failure. As such, it must be prevented by good design, careful selection of SCC-resistant materials, and routine maintenance and inspection. Products that resist this mode of attack include the more highly alloyed austenitic stainless steels such as 317LMN, 904L, and six-percent-molybdenum (Mo) super-austenitic stainless steels, along with duplex and super-duplex stainless steels such as 2205 and 2507.

Galvanized and painted carbon and structural steels resist SCC and can also be used for load-bearing applications. However, these materials must be inspected frequently to ensure the protective galvanizing and coatings are still in place or corrosion can cause rapid deterioration of structural integrity.

Cleaning Stainless Steel

Over-chlorination, inadequate air replacement, and inadequate/improper cleaning increase the aggressiveness of the pool environment. Most corrosion problems can be avoided through proper stainless steel and finish specification, control of the pool environment, and maintenance cleaning. Cleaning procedures as simple as regularly hosing down or wiping down surfaces with fresh water are effective in removing chloride-bearing contaminants and preventing staining.

When chloramines accumulate on stainless surfaces, superficial brown corrosion staining can appear. This mild corrosion will not impair the structural integrity of the stainless steel. Surfaces can be cleaned with appropriate stainless steel cleaners or household cleaning products.[9] However, some stainless steel 'cleaners' may damage the metal or contribute to corrosion so it is important to determine the ingredients. One should avoid products containing hydrochloric acid, chloride compounds, oil, and/or wax, which can cause corrosion or increase chloramine adherence. Steel wool and steel brushes not only scratch the surface, but they can also cause irreparable damage by contaminating the surface. A clean, soft, lint-free cloth or sponge should be used to apply cleaning products.

Very light staining may be removed with a water-dampened cloth or with household vinegar or ammonia cleaning solutions (e.g. window and surface cleaners). More severe staining can be removed with mild abrasive household cleaners that contain 200 mesh or finer calcium carbonate. Dilute oxalic, citric, or nitric acid solutions can effectively remove staining and are sometimes sold as stainless steel rust removers.

Acknowledgement

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Notes

1 These failures have been covered in numerous technical publications, such as the Nickel Development Institute's Stainless Steel in Swimming Pool Buildings, Publication No. 12010 (1995). See also "Stress Corrosion Cracking of Stainless Steels in Swimming Pools" by J. M. Heselmans and E. H. van Duijn (Stainless Steel World, December 2001) and "Stainless Steel in Indoor Swimming Pool Buildings" by Nancy Baddoo and Peter Cutler (The Structural Engineer).
2 See "Effect of chlorine on common materials in fresh water" by A.H. Tuthill et al (Materials Performance Magazine, November 1998).
3 R.A. Stevens and J.T. Holah, "The Effect of wiping and spray-wash temperature on bacterial retention on abraded domestic sink surfaces", Journal of Applied Bacteriology, 1993, Volume 75, pages 91-94
4 J.T. Holah and R.H. Thorpe, "Cleanability in relation to bacterial retention on unused and abraded domestic sink materials", The Journal of Applied Bacteriology, 1990, Volume 69, pages 599-608
5 J.T. Holah, "Sinks of stainless clean best, beat bacteria", Nickel Magazine, June 1990, Volume 5, Number 4
6 Goro Matsuyama, "Demand for Stainless Steel in Construction Field in Japan", Nickel Institute MEP 94-7, August 1995
7 See "Fast Assembly, Low Maintenance" (Nickel Magazine, July 2005).
8 "Stainless steel for outdoor swimming pools – A refurbishment and upgrading initiative in Munich", EuroInox, 2003, ISBN 2-87997-088-1
9 Stainless steel cleaning guidelines are available at both www.stainlessarchitecture.org and www.imoa.info.

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Abstract

Chlorine and a hot, humid environment make indoor swimming pools a very corrosive environment for metals and materials, particularly near ceiling level. Stainless steel has a long and successful history in swimming pool environments and has a lower corrosion rate than other metals. Success is achievable when the right stainless steel and finish are selected, the pool water and air chemistry are carefully controlled, and there is appropriate maintenance.