

Stainless steel in indoor swimming pool buildings

Nancy Baddoo (The Steel Construction Institute) and Peter Cutler (The Nickel Institute) explain how to select materials successfully, based on experimental programmes in the past 10 years designed to avoid failures

Stainless steel has become a popular choice of material in swimming pools; it is an attractive, modern material whilst at the same time being hygienic, easily cleaned and highly corrosion resistant. It has low maintenance requirements, good strength, is easily fabricated and recyclable. It is used both for architectural and structural applications such as pool liners, handrails, ladders, structural components, fasteners, furniture, diving structures, decorative items, and water treatment and ventilation systems (Fig 1).

In 1985, the roof of an indoor pool in Switzerland completely collapsed, resulting in 12 deaths. The roof had been supported by stainless steel tension rods and subsequent investigations showed that chloride stress corrosion cracking had severely weakened them. In response to this, a brief article was published in *The Structural Engineer* in 1988¹ which alerted structural engineers to potential problems in the performance of certain grades of stainless steel in swimming pool buildings.

Since then there have been some other incidents associated with the use of stainless steel in safety-critical, load-bearing applications in indoor swimming pools and leisure centres. One was the collapse of the suspended ceiling of a swimming pool in The Netherlands in 2001 due to the failure of grade 1.4301 (304) stainless steel fasteners, again by chloride stress corrosion cracking (Fig 2). In September 2003, the roof of a hotel swimming pool in Finland collapsed due to the failure of stainless steel tension rods by stress corrosion cracking (again, grade 1.4301 stainless steel). Fortunately, no loss of life occurred in these two accidents.

Experimental investigations carried out since 1985, alongside service experience, confirm that appropriate grades of stainless steel are still excellent materials for both existing and new swimming pools. With due care, stainless steels can provide decades of reliable service in pool equipment. Collaborative guidelines for architects, designers, builders and pool managers were published in 1995². This

article gives up-to-date guidance on grade selection, design, maintenance and inspection for stainless steel components in indoor swimming pool environments, based on results obtained from experimental programmes carried out in the last 10 years.

Swimming pool environments

Indoor swimming pools have changed dramatically over the last 40 years. They have become public leisure facilities with features such as slides, fountains, wave machines, balconies and poolside cafes. There are also more small private pools in hotels and health clubs.

The atmosphere of indoor swimming pools is one of the most aggressive environments to be found in building applications. Higher water temperatures combined with an increase in bather load have led to higher levels of chemical disinfection. Chlorine-based disinfectants are the norm; these react with contaminants introduced by bathers to produce chloramines which are considered to be the most important factor in the corrosion of stainless steel in a swimming pool environment. The air temperature in pool halls is generally held at about 1°C above water temperature. High air temperatures significantly accelerate corrosion.

Atmospheric moisture in pool buildings comes from evaporation of pool water and as droplets from the turbulent water features that have become increasingly common in leisure pools. Higher levels of humidity can lead to condensation in cooler parts of the building and during the cool of the night. Recirculation of pool air (a common method of reducing energy costs) can increase humidity, as well as adding to the build up of contaminants in the atmosphere.

Under the specific temperature conditions near the ceiling, chlorine containing chemical species in vapours from the pool water can condense onto the stainless steel components and dry out. As this is a repeated cycle, very aggressive concentrations of chlorine-containing species may build up. The situation is aggravated by the fact that components may not be easily accessible for regular cleaning and inspection.

Stress corrosion cracking

Stress corrosion cracking (SCC) is a type of localised corrosion characterised by fine cracks which can propagate extremely

Fig 1. Stainless steel is a popular material in swimming pools (Photo courtesy Informationsstelle Edelstahl Rostfrei (ISER), Düsseldorf, Germany)



Table 1: Measures to prevent SCC and minimise its consequences

By the structural engineer	By the pool operator
1) Careful consideration of the corrosion risks and potential for SCC during the design and fabrication of the swimming pool building and components;	1) Carefully maintaining the chemical balance of the pool water by regular monitoring and dosing;
2) Design to avoid corrosion and facilitate inspection and maintenance	2) 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 instructions to bathers
3) Careful selection of appropriate stainless steel grades	3) Maintaining air quality by the correct operation of ventilation and heating plants
4) Adoption of correct fabrication procedures including removal of weld heat tint	4) Regular cleaning to remove dirt and contamination
	5) Regular inspection of safety-critical ¹ components for signs of corrosion and SCC

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

rapidly, leading to failure of the component and potentially the associated structure. Extensive research studies indicate that SCC in swimming pools appears only under a specific combination of three conditions:

- 1) the use of susceptible grades of stainless steel;
- 2) a relatively high tensile stress relative to the yield strength (0.2% proof strength), either from structural loading or present as residual stresses from forming or welding operations during manufacture and installation;
- 3) the presence of a specific aggressive environment. Chlorine containing compounds (by-products of disinfection) may transfer via the pool atmosphere even to surfaces remote from the pool itself. These compounds can produce a highly corrosive film, which can lead to SCC.

Some grades of stainless steel, including 1.4301(304) and 1.4401 (316), have long been recognised as susceptible to SCC, but generally only above 55°C. However, the examples of failure given in the introduction occurred around 30°C, in highly stressed components which had not been washed by pool water or frequently cleaned.

Preventative measures

Corrosion can be effectively controlled by a combination of good design, careful selection of SCC-resistant grades of stainless



Fig 2. Collapsed swimming pool ceiling in The Netherlands (Photo courtesy Stainless Steel World magazine, December 2001)

steel and effective management, including maintenance and inspection. Table 1 gives specific steps that can be taken to prevent the onset of chloride SCC and minimise its consequences when it does occur.

Stainless steel

Stainless steels are iron-based alloys containing at least 10.5% chromium. The corrosion resistance is derived from a thin surface layer of chromium-rich oxide. If the film is damaged by scratching or cutting, it will reform immediately in the presence of oxygen. Although the film is very thin, it is both stable and non porous, thus preventing the steel from reacting further with the atmosphere; it is therefore called a passive layer. It is this characteristic that provides stainless steel with its corrosion resistance, ease of cleaning and durability, and which makes it such a widely used material.

Under certain conditions, however, a damaged film may not easily self-repair –

including high levels of acidity and high concentrations of chlorides that can occur in swimming pool atmospheres. In such circumstances, different forms of localised corrosion may result.

The grades of stainless steel widely used in architecture, building and construction are 1.4301 and 1.4307 (304 types) and 1.4401 and 1.4404 (316 types); they are also the grades specified in swimming pool environments for non-structural applications. Comprehensive guidance on structural design with stainless steel is available both as a publication³ and as web-based software⁴.

Guidance on grade selection

304 and 316 types of stainless steel have a proven track record of excellent performance in non-structural pool water and poolside equipment and remain the most appropriate choice of grade for these applications. Table 2 gives some additional information on composition and strength relating to these grades.

However, the incidents described in the introduction indicate that these grades are not suitable for safety-critical, load-bearing items that are not constantly wetted and in a highly corrosive environment, i.e. components where fracture could result in a risk of injury such as structural components in ceilings or roofs. In particular, components, such as ceiling wire, flume supports, fasteners, cable strapping and hose clips, which are heavily cold-worked are the most vulnerable. Some component

Table 2: Characteristics of the grades of stainless steels used in swimming pools

Steel designation	Nominal composition % ¹				Min 0.2% proof strength ³ N/mm ²	Min ultimate tensile strength ³ N/mm ²	Min elongation after fracture ³ %	General characteristics		
	European Number ²	Popular name	Cr	Ni					Mo	Other
Standard chromium-nickel austenitic steels	1.4301	304			210	520	45	<ul style="list-style-type: none"> • Good corrosion resistance • Excellent formability, weldability and impact strength • Supplied with a range surface finishes 		
	1.4307	304L	19	9.5	Ti	200	500			
	1.4541	321	18	10.5	Ti	200	500			
Molybdenum -chromium-nickel	1.4401	316						<ul style="list-style-type: none"> • Better corrosion resistance compared austenitic steel to standard Cr-Ni grades • Excellent formability, weldability and impact strength • Supplied with a range surface finishes 		
	1.4404	316L	17	12	2.5	220	520		45	
High alloy austenitic steels	1.4539	904L	21	26	4.5	Cu	220	520	35	<ul style="list-style-type: none"> • Very good resistance to uniform corrosion • Very good to exceptionally good resistance to pitting and crevice corrosion • Very good resistance to stress corrosion cracking • Good ductility and weldability
	1.4547 ⁴	6%Mo/254 SMO™	20	18	6-7	Cu, N	300	650	40	
	1.4529 ⁴	6% Mo/926	20	25	6-7	Cu, N	300	650	40	
	1.4565 ⁵	4565	24	16	4	Mn, N	420	800	30	
Duplex	1.4462	2205	22	5	3		460	640	25	<ul style="list-style-type: none"> • High strength • Very good resistance to SCC • Good weldability and impact strength
Superduplex	1.4507 ⁶		25	6.5	3.5	Cu, N	490	690	25	<ul style="list-style-type: none"> • Similar resistance to pitting, crevice corrosion and SCC than the high alloy austenitics • Higher strength but lower ductility than the high alloy austenitics. • Weldable

Notes: ¹The balance of composition is iron in all cases. Carbon is also present, it is controlled to low levels when an L is added to the popular designation, e.g. 316L; ²From EN 10088; ³Mechanical properties for plate from EN 10088-2. Properties may be slightly different from other product forms; ⁴Other '6% Mo' grades are also available with very similar properties; ⁵This grade is not included in EN 10088; ⁶Other superduplexes are also available with very similar properties; 254 SMO is a Registered Trademark of Outokumpu Stainless

Table 3: Guidance on grade selection for different applications in a swimming pool

	Situation	Example	Suitable grades ¹
SCC is not a concern	Fully immersed or thoroughly drenched every session	Pool linings, pool ladders, pool-side rails, some diving board structures	Molybdenum-chromium-nickel austenitic steels are most appropriate, e.g. 1.4401/4, however
	Only splashed with pool water but neither safety-critical nor load bearing	Changing room fittings, lockers etc	standard chromium-nickel austenitic steels are adequate when properly maintained, e.g. 1.4301/7
	In the pool hall atmosphere but neither safety-critical nor load bearing	Decorative panelling	
	Remote from the influence of the pool hall atmosphere	Café and entrance lobby fittings Outdoor pools	
SCC is a concern	Components in the pool hall atmosphere, which are safety-critical and load-bearing but are not washed or cleaned frequently	Brackets for suspended light fittings, loudspeakers, pipework conduits etc	High alloy austenitic steels: 1.4547, 1.4529 and 1.4565 ²
		Supports for suspended ceilings	
		Rod/bar supports for ventilation ducting, water slides etc	
		Wire rope support for water slides etc	
		Structural fasteners etc	

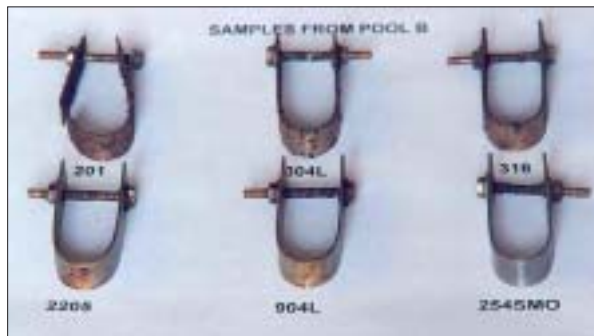
Note:¹See *Guidance on Grade Selection* for further explanation
²Other '6%Mo' grades are also expected to perform satisfactorily in these conditions.

configurations, such as twisted wires and some forms of bolt, nut and washer combinations create a crevice region which increases the risk of localised corrosion attack.

More highly-alloyed grades of austenitic stainless steel than the 304 and 316 types have much greater resistance to SCC. Since 1985 there have been a series of exposure tests looking at the performance of stressed samples of various stainless steel grades in swimming pool atmospheres remote from splashing. Fig 3 shows the appearance of some samples after 6 years exposure.

The results of these tests and other recently published work^{5,6,7} indicate that grades 1.4547, 1.4529 and 1.4565 are suitable for safety-critical and load-bearing components in pool hall atmospheres that are not washed or cleaned frequently. This is in agreement with the requirements of the German building code⁸ (the only regulations concerning grade selection of stainless steels in swimming pools known to the authors). These grades are also used in highly corrosive industrial environments such as the pulp and paper industry, seawater desalination and flue gas desulphurisation (Table 2 gives more information about them). As well as being highly resistant to SCC, the three grades possess the necessary resistance to pitting and crevice corrosion to ensure reliable performance in these highly aggressive environments without regular cleaning. Other '6%Mo' grades are also expected to perform satisfactorily in these conditions.

As a result of their microstructure, duplex grades are more resistant to SCC than the standard austenitic grades⁵. There are some recent examples in the UK of flumes being suspended with superduplex grade 1.4507 stranded wire. It is understood that regular inspections are being carried out and that performance is satisfactory after two years. There are also



examples of duplex grade 1.4462 (2205) giving satisfactory performance in safety-critical, load-bearing swimming pool applications.

Table 3 summarises the current guidance on grade selection given above.

The high alloy grades are available from established stainless steel suppliers in the following product forms: strip, plate, rod, wire and bolt. They cost between three and four times as much as grade 1.4401 (316) and procurement times may be significantly longer than those for common

Fig 3. U-bends after exposure in a swimming pool atmosphere. Note failure of 201 (1.4371) by SCC but very little corrosion on 254 SMO (1.4547)

grades of stainless steel.

Further information on grade selection and procurement is available from The British Stainless Steel Association⁹ and the Nickel Institute¹⁰.

Inspection procedures

Guidance on inspection of stainless steel items is given in a recent UK Health and Safety Executive Safety Information Minute¹¹. This recognises the vital importance of regular, structured inspection of safety-critical, load-bearing components.

Conclusion

Stainless steels remain good materials to choose for swimming pool applications – indoors and open air. Stress corrosion cracking is a hazard which can be avoided. Changes in swimming and leisure, however, demand a more rigorous discipline in the design and management of pools. Appropriate grades of steel must be used, and maintenance and inspection closely controlled.

Recent research has established that certain highly-alloyed grades of stainless steel have improved resistance to stress corrosion cracking where a combination of temperature, humidity and disinfection by-products produce aggressive environments. Where used for safety-critical, load-bearing applications, such grades should still be inspected periodically. Other less corrosion resistant grades should be reserved for areas where stress corrosion cracking is not a potential problem.

Acknowledgment

The authors gratefully acknowledge the many contributions from colleagues in the nickel and stainless steel industries and in particular the assistance of the British Stainless Steel Association.

The authors welcome additional information on the performance of stainless steel in swimming pool buildings in order to build up a more extensive understanding of material behaviour in these conditions and thus ensure that structural engineers are provided with safe, appropriate and cost-effective guidance on grade selections

REFERENCES

1. Page, C. L. and Anchor, R. D.: 'Stress corrosion cracking of stainless steels in swimming pools' *The Structural Engineer*, 66/24, 20 Dec. 1988
2. *Stainless steel in swimming pool buildings* Nickel Development Institute (now Nickel Institute) Publication No. 12010, NiDI, 1995
3. Baddoo, N. R. and Burgan, B. A.: *Structural design of stainless steel* Steel Construction Institute, p291, 2001
4. Website: (<http://www.steel-stainless.org/uksoftware>)
5. Mietz, J. and Isecke, B.: 'Stainless steels for applications in civil engineering' *Stainless Steel World Conference*, p334-339, 2001
6. Sender, U.: *Corrosion and protection in swimming pool buildings* Bulletin 106E, Swedish Corrosion Institute, 1998
7. Oldfield, J. W. and Todd, B.: 'Room temperature SCC of stainless steels in indoor swimming pool buildings' *British Corrosion Journal*, 26/3, p173, 1991
8. Erzeugnisse, Verbindungsmittel und Bauteile aus nichtrostenden Stählen, Sonderdruck 862, Informationsstelle Edelstahl Rostfrei Allgemeine bauaufsichtliche Zulassung Z-30.3-6 vom 5 Dezember 2003
9. BSSA Website: (<http://www.bssa.org.uk>)
10. NiDI website: (<http://www.nidi.org>)
11. *Stress corrosion cracking of stainless steels in swimming pool buildings* SIM 5/2002/18, 2002 Health and Safety Executive, Field Operations Directorate, Food and Entertainment Sector (Also available from the BSSA web site)