The swimming pool at Steenwijk, the Netherlands, the day after the accident (photo 1).

Stress corrosion cracking of stainless steels in swimming pools

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On the morning of 9 June this year, the staff of a nine-year-old swimming pool in Steenwijk, the Netherlands, opened the doors as usual and got the surprise of their life. The whole ceiling and the air channels were lying in the water and round the edges (photo 1). It took some seconds for them to realise that they and their visitors had escaped a human tragedy. It was fortunate that the event had occurred at night, after closing hours. A similar accident, with far worse consequences, had already occurred in Uster (Switzerland) on 9 May 1985, when the entire concrete roof of a swimming pool collapsed, causing 12 fatalities and many injuries.

Problem

Soon after the accident in the Netherlands, its cause became clear. Air channels above the ceiling, weighing hundreds of kilograms, had fallen onto the ceiling, which could not bear the weight of this shock and consequently collapsed as well. The air channels were suspended from stainless steel threaded bars which appeared to contain many stress corrosion cracks. The conclusion was that stress corrosion cracking of the stainless steel bars had caused the accident. In Uster too the accident was caused by stress corrosion cracking in AISI 304 stainless steel bars supporting the roof.

Between 1985 and the present many incidents with stainless steel elements have occurred, most of them unreported. Often, the broken elements were replaced by new elements, again made from stainless steel AISI 304 or 316. Why have we not learned from Uster and the other incidents, at least in the Netherlands, where new swimming pools are still being built with stainless steel 304 or 316 bolts, bars, fasteners, etc.?

An air channel hanging on rusted and cracked stainless steel threaded bars. For unknown reason, the upper part is rusting stainless steel and the lower part is non-rusting galvanised steel (photo 2).

Failure mechanism

The maximum estimated temperature above a swimming pool ceiling is 40°C, lower than the 50–60°C which general corrosion literature states as the minimum temperature at which stress corrosion cracking can occur. Not many corrosion specialists know that the atmosphere in swimming pools, containing the strong oxidator hypochlorite, can cause stress corrosion cracking at much lower temperatures, such as 25–30 °C. For example in Germany and Switzerland, use of stainless steel as a construction element has already been forbidden, and all swimming pools have been checked on use of stainless steel in critical applications such as threaded bars, cables, wires and bolts. At this moment many swimming pools in the Netherlands are being checked and repaired where necessary.

Situation in the Netherlands

Since July 2001 CorrOcean bv has inspected 30 swimming pools in the Netherlands and has come to these astonishing conclusions:

- Six swimming pools were at immediate risk. The air channels were suspended from rusted stainless steel threaded bars (photo 2). Three of those six swimming pools were closed for repair; in the case of the other three, temporary measures (support of the channels) were adopted to reduce the risk until further repair was done.
- Five other swimming pools were not at immediate risk, but elements such as stainless steel bolts in the roof construction, wire hooks on which the ceiling was hanging, and other stainless steel construction elements needed to be replaced as soon as possible.
- In the atmosphere, not under water, most stainless steel rusted. Both AISI 304 (A2) and AISI 316 (A4) elements rusted, not much difference being noted (photo 3).
- Cold-worked stainless steels, such as fasteners, bolts, elements in ceiling hooks, etc., were often found to have stress corrosion cracks below the rust spots (photo 4).
- Most of the problems occurred in new swimming pools; two of these swimming pools were even less than one year old. Swimming pools older than 20 years did not contain critical stainless steel elements. One swimming pool, one year old, had its air channels suspended from rusting stainless steel bars and the steel roof construction bolted with stainless steel bolts.
- Galvanised steel and hot-dipped steel appears to behave much better than stainless steel AISI 304 and 316. Most important, it does not crack, and, moreover, it rusts less than the stainless steels.

Materials selection

The most logical materials selection is use of galvanised and hot-dipped steel. This will start to rust after 2–10 years of use, depending on the atmosphere in the swimming pool and the quality of the zinc layer. To prevent rust, the elements need to be coated, for example with a zinc primer or a decorative coating. In accordance with risk-based inspection philosophy, a simple visual inspection once every 1–3 years will be required. If elements start to rust, they need to be coated.

Regarding use of stainless steels, in Switzerland and Germany the stainless steels Wst. Nr. 1.4529 (24Ni, 20Cr, 6Mo) and 1.4565 (24Cr, 17Ni, 4Mo) are sometimes used. Those high-alloy stainless steels are capable of resisting the swimming pool atmosphere with respect both to rusting and stress corrosion cracking. For stress corrosion cracking resistance, 1.4529 is better than 1.4565, as the first has a higher nickel content (highest SCC sensitivity occurs at about 10% Ni). Duplex stainless steels, which have a relatively low nickel content, may be suitable as well; however, not much experience is available, which means that further testing is required.

Conclusions

- Cold-worked stainless steel AISI 304 and 316 in swimming pool atmosphere is prone to stress corrosion cracking. Use of stainless steel threaded bars, bolts, wires, cables, hooks etc. is dangerous.
- Fifteen years after a serious accident and many other incidents, in several countries, at least in the Netherlands, many swimming pool

Rusted stainless steel AISI 316 construction, after six months of use (photo 3).

constructors, owners and authorities are still unaware of the risks of using stainless steels.

- Swimming pool owners, such as municipals, need to check the risks in their swimming pools.
- In case of any doubt, the materials grade of any construction elements and fasteners needs to be checked.
- All stainless steel critical elements, both stainless steel AISI 304 and AISI 316, need to be replaced by galvanised or hot-dipped steel, or possibly stainless steel Wst. Nr. 1.4529 or 1.4565.
- The atmosphere in swimming pools is very corrosive: much condensation, high hypochlorite content (or other disinfectant) and relatively high temperature (up to 40°C). For this reason, regular inspection of critical elements is required. The high-grade stainless steels 1.4526 and 1.4565 need little or no inspection and maintenance.
- Probably other stainless steel grades, such as duplex or super duplex stainless steel, are suitable as well; however, further testing is required. ◄

Element in stainless steel ceiling hook. The rust spots have been removed. Below rust spots, the material appears to be full of (micro)cracks. The sheet material has been cold-formed and is therefore full of internal stresses (photo 4).

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