NMEC - SEMINAR

ENERGY EVENTS CENTRE

Rotorua

14.11.2018

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PREN – PITTING RESISTANCE EQUIVALENT NUMBER

Stainless Steel is any steel alloy with a **minimum content of 10.5% Chromium.**

Large number of different Types and Grades of Stainless Steel driven by;

(i) Corrosion Resistance,
(ii) Mechanical Properties, Yield, UTS, Elongation
(iii) Weldability,
(iv) Workability,
(v) Heat Treatment
(vi) **COST**

Outokumpu lists 84 standard types of Stainless Steel it produces and stocks.

The degree of Corrosion Resistance between different types of Stainless Steel is not understood.

PREN - Pitting Resistance Equivalent Number.

Pitting Corrosion

The Pitting Resistance Equivalent Number (PREN) - a measure of the relative pitting corrosion resistance of stainless steel in a chloride-containing environment.

Higher PREN values indicate greater corrosion resistance. The formula for PREN is:

$$PREN = \%Cr + 3.3 * \%Mo + 16 * \%N$$

PREN Pitting Resistance Equivalent Numbers						Cr	Chromium				For Seismic Elastic Design – Category 4					
10.09.2018						Mo	Molybdenum				Maximum Yield = 450MPa					
						N	Nitrogen				Maximum UTS = 500MPa					
General Formula	PREN = Cr% + 3.3Mo% + 16N%					Ni	Nickel				Minimum Elongation = 15%					
Duplex Formula	PREN = Cr% + 3.3Mo% + 30N%					C	Carbon				Maximum Yield to UTS Ratio = 90%					
Type	**Type**	**C% Low**	**C% High**	**Cr% Low**	**Cr% High**	**Mo% Low**	**Mo% High**	**Ni % Low**	**Ni % High**	**N% Low**	**N% High**	**PREN Min**	**PREN Max**	**Yield Mpa**	**UTS Mpa**	**Yield/ UTS %**
445M2 (2D) (Wakefield Metals – Nisshin Steel)	Ferritic	0.00	0.01	22.1		1.2						26.1	0.0	343	510	67%
430 (Atlas Steels Australia)	Ferritic	0.00	0.12	16.0	18.0				0.8			16.0	18.0	205	450	46%
NSSC 550 (Maryland Mertics)	Martensitic	0.10	0.20	12.5	14.0	1.8	2.3	1.0	2.4	0.1	0.2	19.2	24.0	770	1000	77%
410 (as per AZO Materials)	Martensitic	0.00	0.15	11.5	13.5							11.5	13.5	275	480	57%
420 (as per AZO Materials)	Martensitic	0.00	0.15	12.0	14.0							12.0	14.0	345	655	53%
17-4PH (HH1150 Per Atlas Steels)	Austenitic	0.00	0.07	15.0	17.5			3.0	5.0			15.0	17.5	1000	1105	90%
304 (Per Atlas Steels Australia)	Austenitic	0.00	0.07	17.5	19.5			8.0	10.5		0.1	17.5	21.1	205	515	40%
A2-70 (Per British SS Assn.)	Austenitic	0.00	0.10	15.0	20.0			8.0	19.0			15.0	20.0	450	700	64%
A2-80 (Per British SS Assn.)	Austenitic	0.00	0.10	16.0	18.5	2.0	3.0	10.0	15.0			22.6	28.4	600	800	75%
316 (Atlas Steels Australia)	Austenitic	**0.00**	**0.08**	**16.0**	**18.0**	**2.0**	**3.0**	**10.0**	**14.0**		**0.1**	**22.6**	**29.5**	**205**	**515**	**40%**
A4-70 (Per Bumax)	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	450	700	64%
A4-80 (Per Bumax)	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	500	800	63%
Bumax 88 (3mm – 36mm)	Austenitic	0.00	0.03	16.5	18.5	2.5	3.0	11.0	14.5			24.8	28.4	600	800	75%
Bumax 109 (>12mm)	Austenitic	0.00	0.03	16.5	18.5	2.5	3.0	11.0	14.5			24.8	28.4	600	1000	60%
560HTR/316 <22mm (Per Kinzi)	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	700	875	80%
560HTR/316 >22mm – 24mm	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	560	802	70%
560HTR/316 >24mm - 52mm	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	515	650	79%
560HTR/316 >52mm	Austenitic	0.00	0.08	16.0	18.0	2.0	3.0	10.0	14.0		0.1	22.6	29.5	460	620	74%
262/260 <5/8” (Per Kinzi)	Austenitic	0.00	0.03	16.5	18.0	2.5	3.0	10.0	14.0		0.1	24.8	29.5	310	515	60%
262/260 5/8” - 1-1/4”	Austenitic	0.00	0.03	16.5	18.0	2.5	3.0	10.0	14.0		0.1	24.8	29.5	205	515	40%
262/260 M27 – M56	Austenitic	0.00	0.03	16.5	18.0	2.5	3.0	10.0	14.0		0.1	24.8	29.5	262	515	51%
6Mo 254SM0 (Hague Fasteners UK)	Austenitic	0.00	0.02	19.5	20.5	6.0	6.5	17.5	18.5	0.18	0.2	42.2	45.5	300	650	46%
448	Duplex	0.00	0.01	28.0	30.0	3.5	4.2					39.6	43.9	448	620	72%
2205 (S32205) (Atlas Steels Australia)	Duplex	0.00	0.03	22.0	23.0	3.0	3.5	4.5	6.5	0.1	0.2	36.1	40.6	450	655	69%
2304 1.4362 Lean Duplex	Duplex	0.00	0.02	22.0	24.0	0.1	0.6	3.5	5.5	0.1	0.2	23.8	32.0	400	600	67%
2507 (Atlas Steels Australia)	Super Duplex	0.00	0.02	24.0	26.0	3.0	5.0	6.0	8.0	0.2	0.3	41.1	52.1	550	795	69%

A PREN value of 32 is considered the minimum for sea-water pitting resistance.

A PREN value greater than 40 is totally resistant against pitting and crevice corrosion in sea water.

Mild Steel has a Carbon Content 0.05% - 0.25%

Medium Tensile Steel has a Carbon Content 0.30% –

High Tensile Steel has a Carbon Content 0.45% – 0.7

File Name; PREN Pitting Resistance Equivalent Numbers 2018.05.07

316 Grade is not the Marine Grade, note the WIDE PREN RANGE of 316 Stainless Steel.

For the Passive Layer to work it must be clean and there must be FREE OXYGEN present.

Compare Cr_2O_3 Chromium Oxide and Fe_2O_3 Ferric Oxide
Fe_2O_3 appears as an orange film, Cr_2O_3 is a Passive bright shiny layer 1/100,000 of a human hair thick which is easily damaged but repairs quickly if Oxygen is present. Take away Oxygen and corrosion commences as intense localised “spots” where inclusions of Sulphur, Silicon and Phosphorus occur in the skin of the alloy.

Ferritic, Martensitic and Austenitic Stainless Steels cannot cope with Chloride (Cl) or Sulphur (S) loaded environments.

Sesoc Journal, Volume 28, September 2015 – “Fatal Accident in Dutch Swimming Pool Caused by Environmentally Cracked Bolts”

FATAL ACCIDENT IN DUTCH SWIMMING POOL CAUSED BY ENVIRONMENTALLY CRACKED BOLTS

Reprint through kind permission NACE: Corrosion 2013 Conference
Note: Paper has not been rerefereed

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ABSTRACT

In November 2011 a 5 month old baby sadly got killed in a Dutch indoor swimming pool because 2 speakers and a speaker frame landed on her head. The speakers fell from a height of 5 meters after a stainless steel bolt was broken due to environmental cracking. Worldwide there have been many incidents, and several accidents, with cracking stainless steels in the swimming pool atmosphere. In 1985 in Switzerland 12 people were killed by a cracked stainless steel element that caused the collapse of a swimming pool roof.

This paper will describe how this accident could happen and what has been done in the Netherlands since 2001, when the entire ceiling and air channels came down in another swimming pool (luckily this occurred during closing time). Further a new document MIS1203-2012 will be discussed: "Materials Selection and Inspection of Fasteners and other Loaded Elements in the Indoor Swimming Pool Atmosphere".

INTRODUCTION

This paper is mainly based on my personal experience with technical inspections in Dutch swimming pools. In the Netherlands every town or village has one or more public swimming pools. About 700 large swimming pools are owned by authorities such as municipalities and at least 1500 smaller public indoor swimming pools are owned by hospitals, revalidation centres, schools, hotels, camping sites and the recreational sector. As a corrosion specialist, I was involved in this subject in 2001 when the entire ceiling and air channels collapsed in a swimming pool in Steenwijk (the Netherlands) [2]. As you can see on figure 1, this luckily happened during closing time.

In the day time normally hundreds of people are present in such public swimming pools and one can imagine what a tragedy this would have been if the swimming pool had been opened during the collapse. In 1985 a similar accident in Switzerland caused a tragedy in which 12 people were killed and 19 people were injured. This accident occurred during opening time of the public swimming pool (see figure 2).

Figure 1: 1 June 2001, the morning after the collapse of ceiling and air channel in the indoor swimming pool at Steenwijk (NL). The collapse was caused by environmental cracking of stainless steel threaded bars. (Photo courtesy: Steenwijkerland municipal).

PAPER CLASS & TYPE: GENERAL NON-REFEREED

Figure 2: 9 May 1985, collapse of roof elements and ceiling during opening time of the swimming pool in Uster, Switzerland. Twelve people were killed and 19 were injured. The collapse was caused by environmental cracking of stainless steel elements in the roof construction.

It shows that, at least in Europe, the building industry is very national oriented because in the Netherlands until 2001 the building industry and authorities were unaware of the stainless steel risks in swimming pools. Even up to 2012 builders and authorities have organized this issue in an amateurish way. In most scopes and specifications for new-to-build swimming pools statements are made such as: "the hanging elements of the ceiling and air channels must be corrosion resistant". Or for critical M16 bolts in the roof construction it is stated: "The bolts must be resistant in accordance with corrosion class C4 or higher". Of course such general statements often lead to a selection of the dangerous stainless steels from groups AISI 304 or AISI 316. That is why even today use of new stainless steels in swimming pools can be noted. The problem is that critical elements have not been specified sufficiently due to lack of a proper standard or directive for materials selection and inspection.

In 2001-2003 I did inspections by myself, besides as a responsible manager I have seen hundreds of reports that were made by our inspectors. During an inspection all relevant materials are being inspected on materials selection and condition with regard to corrosion decay. Most swimming pools take proper actions, but others fail for many reasons such as bureaucracy, absence of a capable maintenance department or improperly judged risks by owners and the management.

This led to an unfortunate accident in Tilburg (the Netherlands) in November 2011. Two speaker boxes and a speaker frame, weighing all together some 50 kg, came down from a height of 5 meters on a 5 month old baby and her mother. This accident sadly killed the baby and wounded the mother. The boxes came down because of rupture of stainless steel bolts, caused by environmental cracking[1]. Three inspection reports (of 2006, 2009 and April 2011) point out that the stainless steel parts should be replaced by galvanized steel immediately.

This paper will describe the cracking mechanism in the swimming pool atmosphere and the general situation in the Netherlands in 2012. Further a proposed standard [1]. for materials selection and inspection of critical elements in the swimming pool atmosphere will be discussed.

CORROSION IN INDOOR SWIMMING POOL ATMOSPHERE

This paper mainly deals with the swimming pool atmosphere and not with the swimming pool water or the 'splash zone'. The splash zone is the zone around the pool where wet people walk, water splashes on the floors and where employees clean the floor and surroundings with fresh water every day. In the splash zone as compared with the atmosphere, corrosion behaviour of zinc coated materials versus stainless steel materials differs completely. This leads to different materials selection in these two zones.

The swimming pool atmosphere is at a larger height, up to invisible places high above ceilings. This atmosphere is often very corrosive because of the high degree of humidity. The relative humidity normally is 50-75% but in many cases condensation has been noted in places which are invisible and/or very difficult to get access to. Since the 1990s most public swimming pools have been transformed into a 'tropical swimming paradise', resulting in increasing atmospheric temperatures and humidity. In order to save energy sometimes the temperature is lowered during the night, which leads to condensation on metal elements such as bolts, threaded bars and hangers for ceilings. The atmosphere is very corrosive to unprotected or insufficiently coated steel as can be derived from figures 3 and 4.

Figure 3: Heavily-rusted H-profile after 12 years of use.

Figure 4: Completely rusted ceiling hanger after 6 years of use. The sheet was not coated, or had been provided with only a minor black organic coating. Officially such hangers are not allowed for swimming pools, but only suitable for dry buildings such as offices.

[1] *The police investigation report has not been published yet. This is the unofficial cause.*

SS Bracing and Fasteners in enclosed swimming pools. - Sodium Hypo-chlorite reacts with human skin, sweat and urine to form Chloramines which condense up as Hydrochloric Acid when the Pool is cooled at night to save power- causes Stress Corrosion Cracking - Samples

Otahuhu Recreation Centre Swimming Pool – 560 Grade SS Braces replaced after 15 months,
Henderson Swimming Pool Ceiling came down early November 1998,
Stanmore Bay Swimming Pool – all SS Droppers being replaced,
Auckland City now checking SS Braces and Fasteners,

6Mo Fasteners or Duplex Grade Fasteners must be used with Duplex Grade Braces, Frames, Droppers and Supports.

316 Grade SS Fasteners used in Waste Water Outfall – 316 Grade SS Bolts and Nuts etc. failed in 18 months.
The Engineering Practice involved advised that all their Professional Indemnity Claims result from 'Failed Stainless Steel'!

NZ Building Code requires 316 Grade SS to be used within 50 metres of a Geothermal Bore.

316 Grade used as Covers for Air conditioning Plant in Rotorua failing within 12 months – solution was to Electropolish.

For improved Corrosion Resistance of Stainless Steel SMOOTHER IS BETTER.

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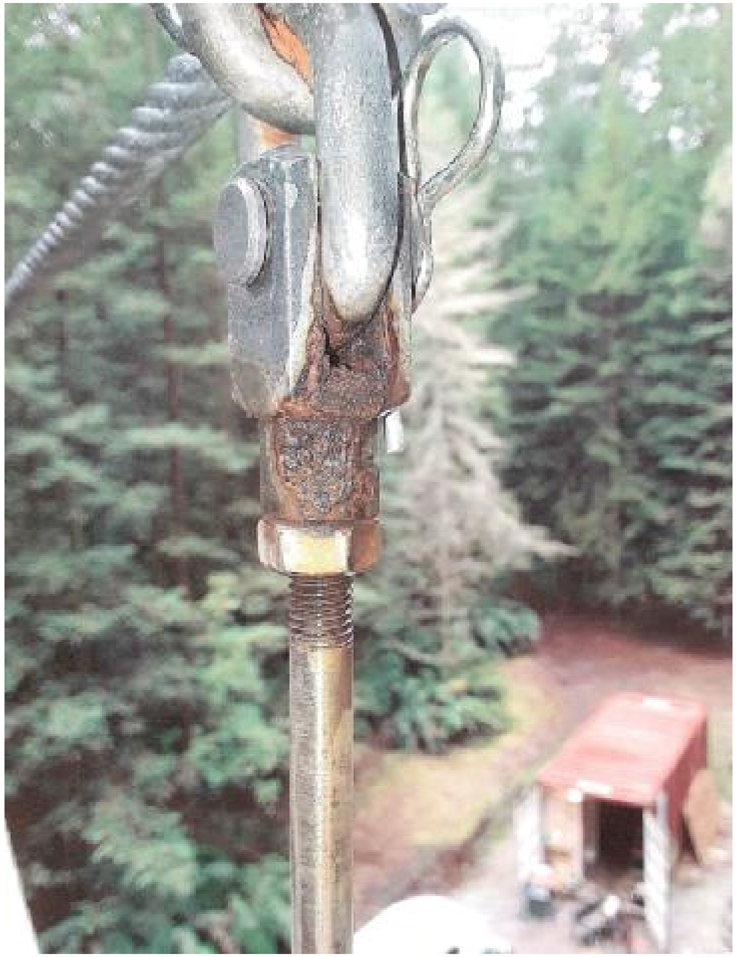
Galvanic Corrosion of Redwood Skyway Fittings in Rotorua



NZ Building Code requires *Stainless Steel* to be used within 500 metres of the High Water Mark.

Thus low PREN Fasteners, Brackets and Braces can be used.

Currently trialling 304 Grade Stainless Steel Reinforcing in concrete “Jump Blocks” under the Beehive in the event of an Earthquake.
Wellington Council is considering the required use of SS Reinforcing Bar in concrete in contact with salt water.

Pier in Mexico – 70 years old used 304 Grade Stainless Steel Reinforcing Bar in poorly placed low quality concrete is still operating.
A replacement Pier built alongside using Carbon Steel Reinforcing lasted 11 years.

Nordic Innovation Centre Project – 04118 Project Report by Gro Markeset, Steen Ronstam and Oskar Klinghoffer "Guide for the use of stainless steel reinforcement in concrete structures".
Bahrain Financial Harbour Sky Scrapers Design Service Life is 60 years.
Great Belt Link, Denmark (Tunnel and Bridges) Design Service Life is 100 years.
Messina Strait Bridge with a 3000m Main Span Design Service Life of 300 years.

There is an unfounded fear of using stainless steel and carbon steel together in the same concrete structure.
It is possible to use Stainless Steel Reinforcing in the outer layer and Carbon Steel Reinforcing in the inner section of a Concrete Member thereby reducing the cost.

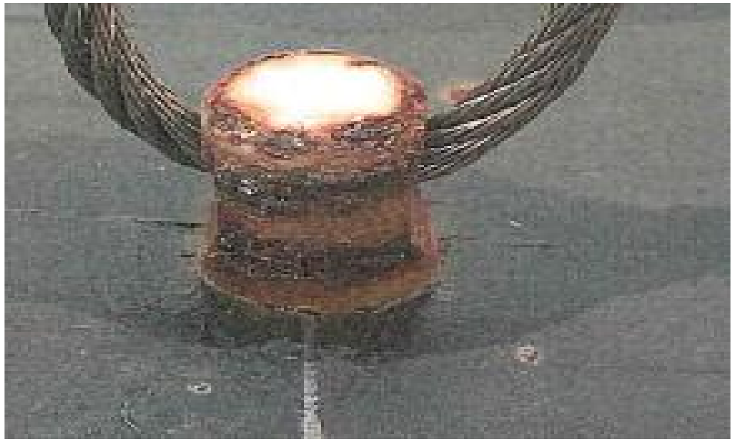
Australasian Corrosion Association Meeting - Galvanic protection being installed on SS Plates on a wharf, should be using a Duplex Grade of SS not 316 Grade.

316 Grade Screws used in Boardwalk at Maldive Islands – Crevice Corrosion,

304 Grade hinge in a cupboard at Piha corroding badly – an open bottle of a Chlorine based cleaner.

Duplex Grade Tensioners for NZ Radio Aerials – note the use of Tefgel.

Carbon Steel Contamination and Installation matter;
Anzor 316 Grade Eyelets in Kerikeri, the Customer wrote - “It should be of no relevance how these were installed as stainless does not rust! The eyelets with the groove react to magnet (we have just discovered) which proves they are not stainless.”



304 Grade Corner Soaker's corrode under Acrylic paint, - lack of Oxygen.