

## The Suitability of Stainless Steels for Road Constructions



### Dear Reader

Already the ancient Romans realized the necessity of high quality roads and other infrastructure for keeping their empire together. Good communications are essential parts of a civilization, as exemplified by the Roman roads all around the Mediterranean, or the Inca trails in Southern America, both constructions of which parts are still in use today, although the civilizations who once built them have long since passed into the history books. Today's infrastructure is maybe not designed to last for thousands of years, but careful selection of materials, makes it possible to significantly prolong life-cycles and to reduce maintenance. Another important aspect is the amount of material used. With high-strength lean duplex alternatives, it is possible to significantly reduce weight in bridges and other load-bearing constructions and to make new leaner designs. So why not go for a long lasting alternative in lean infrastructure design – the stainless option?

Sincerely,  
*Claes Olsson, PhD*  
Acom editor

# The Suitability of Stainless Steels for Road Constructions

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## Abstract

Ten different stainless steel grades were exposed for two to four years along Swedish roads representing different geographical locations and climate regions: north, middle and south of Sweden, de-icing frequency and traffic intensity. The test sites have covered open roadsides with cleaning in form of rainfall, shielded roadsides without rainfall, on bridges and in a tunnel. The exposures include road bridges crossing electrified railways implying a need for grounding of railing posts to the rebar web. The discussion also includes examination of stainless steel components after use in tunnel environments, almost twelve years testing of lampposts, and the use of stainless steel for rebars.

All tested stainless steels can be used independent of location for all covered applications if some superficial staining can be accepted, with the exception of tunnel environments where certain precautions might be required. It is also suggested that bridges are made of duplex stainless steel due to the large cost saving potential.

A modification of EN ISO 12944-2 is proposed to facilitate selection of stainless steel for components along roadsides.

## Introduction

Increased traffic intensity, more strict safety aspects and increased maintenance costs have developed a pronounced interest from road authorities to use more corrosion resistant materials for a variety of structures. Light weight lamp posts that are corrosion resistant enough to be maintenance free for maybe half a century, strong enough to carry the required electric fittings, but still soft enough not to demolish a car when being hit, crash barriers having the same characteristics, electric boxes, cable trays and load bearing fasteners and other devices in tunnels and on bridges are all examples of such items. Safety railing posts and reinforcement bars are others.

Architects and design engineers selecting materials for road environment components have often access to tools in form of classification systems for painted or coated mild steel and aluminium components to be used, but lack information about the suitability of different stainless steels.

The Swedish Corrosion Institute (SCI) has, together with Outokumpu, the Swedish Road Administration and some other sponsors, investigated the suitability of different materials when exposed to conditions along roads, on bridges, and in tunnels [1].

Parallel to this study Outokumpu tested ten stainless steel grades at the same test sites during the same time, but since these studies were finalised after two years only Outokumpu also run another parallel test in one of the tunnels with an exposure time of four years. The purpose was to investigate any change in corrosion performance after such a prolonged time. The paper contains a summary of all these investigations, excluding, however, non-stainless steel materials

The discussion also includes a study of stainless steel reinforcement bars and three other investigations performed on materials for lampposts, for railing posts on road bridges crossing electrified railways and in tunnel environments. And there is finally an attempt to apply the achieved results on existing classification systems for coated or painted mild steel.

## EXPERIMENTAL

### Test material

Specimens from ten different stainless steel grades have been used, Table 1. Different products have been included in the exposures and the specimens have originated from different heats. However, the variations in chemical composition between different heats have been small and the values given in table 1 are representative mean values.

Out of the grades included in table 1, three, Outokumpu HyTens® (301), 316L and 316 high Mo, were used for the four year exposure in one of the tunnels (Stockholm, the Söderledstunnel).

The PRE-number, occasionally called PREN to emphasise the presence of nitrogen, can be used for a rough estimate of the relative resistance to localised corrosion (pitting or crevice), i.e. the types of corrosion that are most likely to occur on stainless steel in the investigated environments. The higher the PRE-number, the better resistance. A difference of more than five units means a significant difference in localised corrosion resistance.

The study has also covered specimens with different surface finishes, Table 2, welded, grades 201, 316L and LDX 2101, and non-welded specimens and specimens with and without crevice formers, Figure 1. The welding has been performed either as TIG (tungsten inert gas) or MMA (manual metal arc) with recommended welding consumables [1]. Post weld cleaning by pickling in mixed acid for 316L and LDX 2101 and mechanical cleaning for 201 (brushed with Scotch Brite). Temper rolled material (301) has been tested with 90° bends and as Hex-A-Beams®, Figure 2.

**Chemical compositions (% by weight) and PRE-numbers<sup>1</sup> of the stainless steel grades tested.**

Table 1

Outokumpu	EN	ASTM	Cr	Ni	Mo	Others	PRE <sup>1</sup>
HyTens® 4310	1.4310	301	17	7.1	–		17
4307	1.4307	304L	18	8.2	0.3	0.07N	20
4404	1.4404	316L	17	11	2.1	0.06N	25
4436	1.4436	316hMo <sup>2</sup>	17	11	2.6	0.06N	27
254 SMO®	1.4547	S31254	20	18	6.1	0.21	43
LDX2101®	1.4162	S32101	22	1.5	0.3	5Mn, 0.22N	26
2304	1.4362	S32304	23	4.8	0.3	0.09N	25
2205	1.4462	S32205	22	5.7	3.1	0.17N	35
SAF 2507®	1.4410	S32750	25	6.9	3.8	0.29N	41
4372	1.4372	201	17	4.5	–	6.7Mn, 0.20N	20

1. PRE (Pitting Resistance Equivalent) = %Cr + 3.3 x %Mo + 16 x %N.

2. "hMo" to indicate the elevated level of molybdenum.

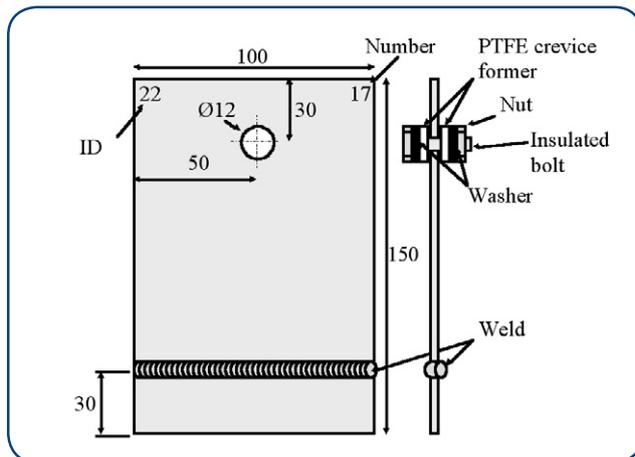
® Trademarks registered by Outokumpu and Sandvik, respectively.

**Surface finishes. The deco rolled surface had different roughness values on each side.**

Table 2

Condition	R <sub>a</sub> (µm)
Temper rolled	0.07–0.16
Cold rolled, skin pass	0.38–0.48
Pattern rolled	–
Deco rolled	0.14–2.19
Hot rolled	3.15–6.02
Cold rolled, brushed and pickled	0.09–0.22

**Fig. 1** Welded specimen with crevice former.

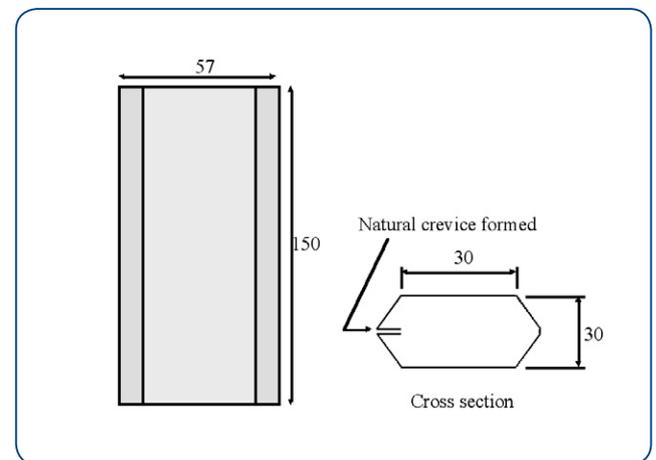
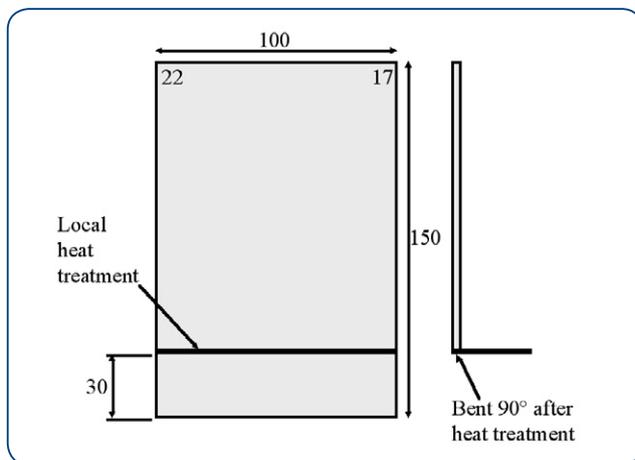


The prolonged tunnel exposure was performed with non-welded specimens, but apart from that, the same type of set-up was applied.

U-bends from all steel grades with the exceptions of 316hMo and SAF 2507 were tested at one location, Söderledstunneln, see test sites below, to evaluate the risk of stress corrosion cracking (SCC).

The specimens have been mounted on Plyfa sheets, which in turn have been mounted close to the roadway as shown in Figure 3.

**Fig. 2** Specimens of temper rolled 301, 90° bends (left) and Hex-A-Beams® (right).



**Fig. 3** Plyfa sheets with specimens, Borås (left) and the Öresund bridge (right).



**Fig. 4** Map of Sweden. Location of test sites.



### Test sites

There were eight test sites at seven locations in different parts of Sweden, Figure 4, which should cover typical road environments including geographical location, climate, de-icing frequency and traffic intensity. The test sites are briefly described below while details are presented in Table 3.

- Borås, main road 40, inland, far from the coast.
- Gothenburg, Swedish west coast, but not directly on the shore, Lundbyleden at Bäckebolet.
- Öresund, the bridge crossing the strait between Denmark and Sweden. One set of specimens at the roadside, another underneath the bridge, close to a railway.
- Öland, the bridge crossing the strait between the mainland and the island Öland, Baltic Sea.
- Stockholm, inside the Söderledstunnel. No de-icing inside the tunnel but cars are bringing salt from the outside road.
- Höga Kusten, bridge crossing a bay of the Baltic Sea, but still not directly on the coastline.
- Svartnora, bridge crossing a strait between the mainland and an island in the Baltic Sea.

### Exposure time

The exposure lasted from late 2002 to late 2004, i.e. an exposure time of two years for most of the specimens. The extended tunnel test specimens were dismantled after four years of exposure in December 2006.

### Test site locations, traffic intensity and environmental description.

#### (1) No de-icing within the tunnel but brought in by circulating traffic.

Table 3

Location	Vehicles/day	De-icing events	Distance from roadway (m)
Borås, inland main road	15,000	250	2.7
Gothenburg, city road	40,000	300	1.2
Öresund bridge, roadside	8,000	170	3.1
Öresund bridge, underside	–	–	–
Öland bridge, coastal	14,000	253	0.3
Stockholm, tunnel road	70,000	0 <sup>1</sup>	2.1
Höga Kusten bridge, coastal	4,000	718	1.5
Svartnora bridge, coastal	400	5	0.5

**Results from two years exposure of stainless steel specimens in road environments at different locations in Sweden. The number 0 means no corrosion; p64/cc40 means pits of max 64 µm (2.5 mils) and crevice corrosion to 40 µm (1.5 mils) depth. n.t. means: "not tested"**

Table 4

Grade	Borås	Gothenburg	Öresund, road side	Öresund, underside	Öland	Stockholm	Höga Kusten	Svartnora
301	p64/cc40	p25/cc29	p33/cc64	p53/cc112	p28/cc100	p51/cc35	p42/cc80	cc29
304L	n.t.	n.t.	n.t.	cc48	n.t.	n.t.	n.t.	0
316L	0	p52	0	cc120	0	p52/cc172	p27	0
316hMo	0	0	0	n.t.	0	p60/cc65	0	0
254 SMO	0	0	n.t.	n.t.	n.t.	0	n.t.	n.t.
LDX 2101	0	0	0	0	0	n.t.	0	0
2304	0	0	0	cc40	0	n.t.	0	0
2205	0	0	0	0	0	0	0	0
SAF 2507	0	0	n.t.	n.t.	n.t.	0	n.t.	n.t.
201	n.t.	n.t.	cc65	cc138	cc75	n.t.	0	cc37

## RESULTS

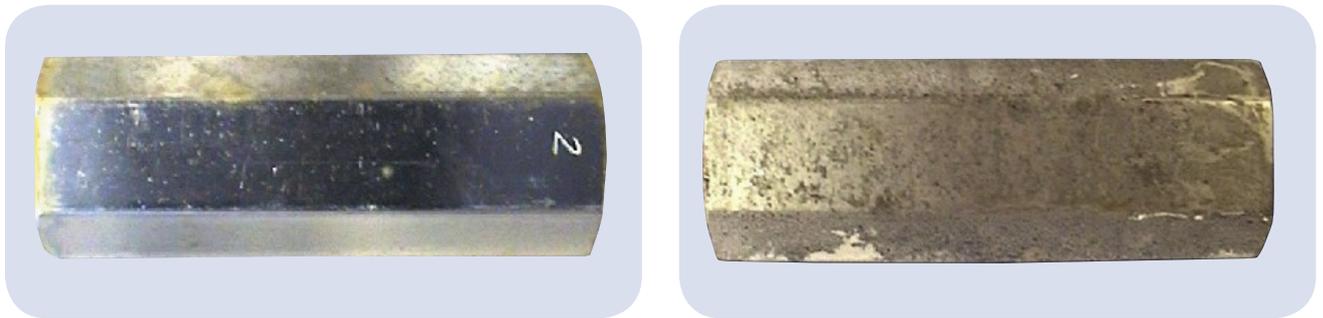
### 3.1 Two year testing

None of the U-bends had suffered any cracking. The other results are summarised in Table 4.

Rust stains without significant corrosion have been excluded. The criteria for significant corrosion is based on ASTM G 48, which states that attacks more shallow than 25 mm (-1 mil), should be neglected.

The appearance of the least corrosion resistant material, 301, after exposure at the most hostile test locations, i.e. underneath the Öresund Bridge and inside the Söderleds-tunnel in Stockholm, is shown in Figure 5. The specimens have not been cleaned after the test.

**Fig. 5** Hex-A-Beams® made of 301 after 2 years underneath the Öresund bridge (left) and inside the Söderledstunnel



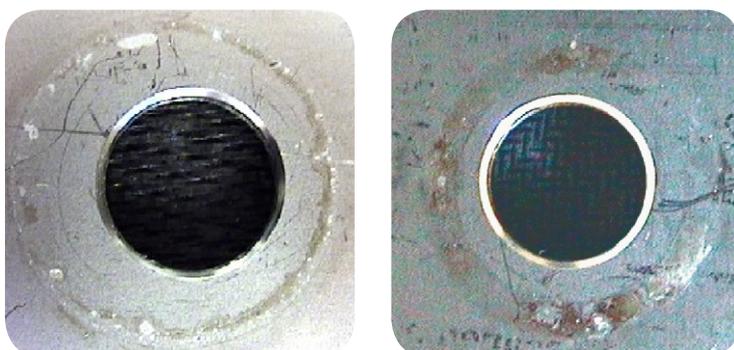
A close view upon the specimens of 316L exposed at the same locations is shown in Figure 6. The specimens have been cleaned in order to facilitate the evaluation. Both specimens show some slight etching only due to crevice corrosion. The slightly deviating appearance of the tunnel specimen depends on some rust formation due to insufficient cleaning.

Also if different surface finishes and welded and non-welded specimens were tested there were no differences in result, which could be referred to the different executions. There was, however, an indication that the rougher surface of hot rolled plate was slightly more susceptible to corrosion than the other finishes

### Four year testing in a tunnel

As can be seen in Table 5, the corrosion appearing on the three grades after the extended test time is still very shallow and could be defined more as a very slight etching considering a max depth of 90 µm after 4 years, i.e. about 20 mm/year or < 1 mpy, see Figures 7–10. The scratches are caused by gravel spray from the traffic.

**Fig. 6** The most severely attacked specimens of grade 316L after 2 years exposure underneath the Öresund bridge (left) and inside the Söderleds-tunnel (right), showing crevice corrosion of 0.11 and 0.17 mm depth respectively.



**Results from the 4 year exposure in the Söderledstunnel.**

Table 5

Grade	Pitting	Crevice corrosion
301	75 µm	70 µm
316L	90 µm	63 µm
316hMo	79 µm	No

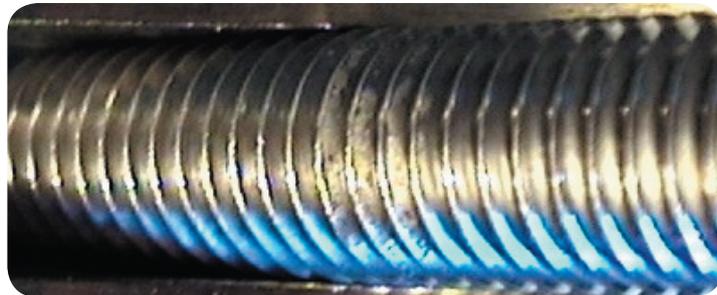
**Fig. 7** Hex-A-Beams® made of 301 after 4 years in the Söderledstunnel before (left) and after cleaning.



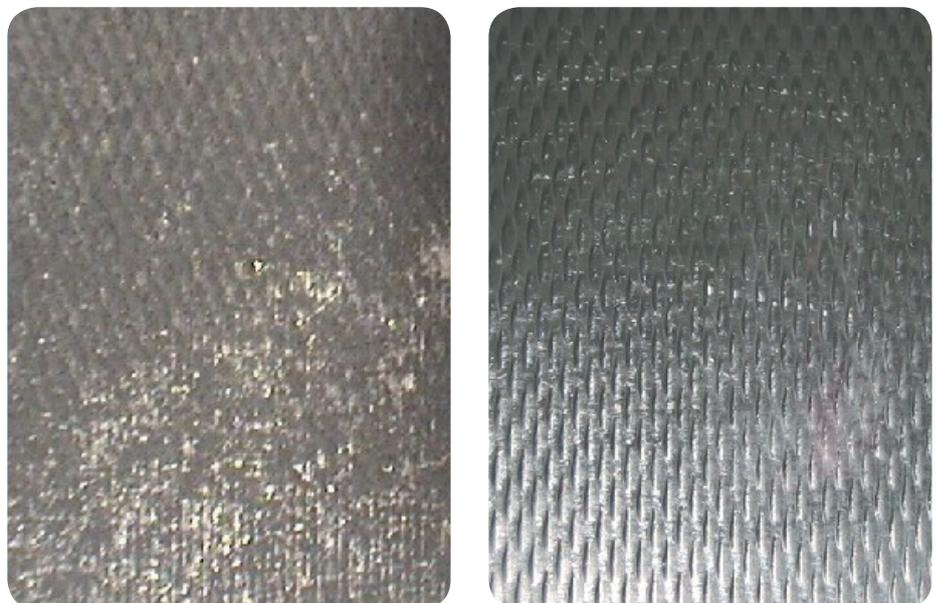
**Fig. 8** Specimens made of 316L after 4 years in the Söderledstunnel before (left) and after cleaning.



**Fig. 9** Bolt made of 316L with slight crevice corrosion on threads.



**Fig. 10** Pattern rolled 316L (high Mo) after 4 years in the Söderledstunnel before (left) and after cleaning.



## DISCUSSION

### General

First of all, it should be established that when corrosion has occurred, it is very shallow. The maximum depth measured on any specimen is 0.17 mm crevice corrosion on 316L after 2 years of exposure in the tunnel, i.e. a penetration rate of less than 0.1 mm/year (< 5mpy). The extended testing time did not develop any deeper attacks, neither on this grade, nor on the others.

When pitting or crevice corrosion is developed in a stainless steel immersed in seawater or another high chloride containing solution the penetration rate is at least ten times higher, which indicates that the corrosion occurring has not been a continuous process, but rather intermittent. The attack has started to grow, then stopped during dry periods and then possibly continued when exposed to wet conditions again.

It can also be established that the conditions inside the Söderledstunnel are very corrosive causing by definition significant corrosion not only on grade 301, which is expected, but also on 316L, both with normal and elevated molybdenum contents. The reason is a combination of de-icing salt brought into the tunnel with the traffic and lack of cleaning from rainfall.

The conditions underneath the Öresund bridge are similar to those inside the tunnel, i.e. the molybdenum-alloyed grade 316L has suffered significant pitting attacks and also the duplex grade 2304, while the roadside conditions can be described as almost harmless. This emphasises the importance of cleaning, which can be either from rainfall or the result of a manual maintenance. And it also emphasises that airborne chlorides or chloride-containing mist may cause staining, but not really any severe corrosion.

The rating of the remaining test sites, Svartnora (least corrosive conditions), Borås, Öresund roadside, Öland, Höga Kusten and Gothenburg can be explained by variations in traffic intensity and frequency of de-icing and it also confirms the low contribution from air-borne chlorides.

Out of the steel grades tested the austenitic grades 301, 304L and 201 are the least resistant grades, which is just according to the text book considering the low content of alloying elements and the PRE-numbers given in table 1. They have suffered corrosion at every single test site. The corrosion can, however, not be regarded as severe in any case, it is rather a matter of appearance, if staining can be accepted or not.

It could be emphasised that for the type of applications discussed there is no difference between 304 and the low carbon version 304L. The present study covered 304L while there are references below also to 304.

### Roadside

The results from the present study are well in agreement with previously presented results from the Swedish Corrosion Institute (today KIMAB) covering exposures of lampposts for close to 12 years [2]. According to this study the results gave a lifetime prediction of at least 50 years, even for a low-alloy grade such as 304.

However, there is a comment in that report about the risk of crevice corrosion on 304 if being inserted in a concrete footing. That comment is not supported by the test results and could be neglected since the concrete will ensure a pH value high enough to prevent crevice corrosion on stainless steel.

If the results from the present study are combined with the previous results there is no doubt that low-alloyed grades such as 301 and 304 can be used for roadside components having a predicted service life time of 50 years if some staining due to superficial corrosion can be accepted and if the following precautions are considered,

- The component should be placed so regular cleaning can occur, either by manual maintenance work or natural rainfall.
  - Design should minimize presence of crevices where dirt and, above all, salt can be collected.
- If the location is far from the sea, i.e. at least several kilometres, and if there is almost no de-icing, the service life will exceed 50 years without these precautions.

This is independent of whether the component is a lamppost or a crash barrier or a safety railing post.

If the location of the component implies shielded conditions, i.e. no possibility for cleaning, neither by rainfall nor by manual maintenance, a more corrosion resistant grade such as LDX 2101, 2304 or 316L will be required.

### Bridges

The conditions for bridges are mainly governed by the same parameters as other roads, i.e. traffic intensity, de-icing frequency and probably also climate. The nearness to the sea seems to be less critical; at least when the roadway is at such a height that there is no exposure to direct splashes from waves. This implies rather harmless conditions for stainless steel if cleaning, manual or by rainfall, is conducted.

However, components in shielded areas must either be manually cleaned or made of stainless steels higher alloyed than conventional 304L, i.e. LDX 2101, 2304, 316L or 2205.

There is also a special type of bridges, i.e. road bridges crossing railways, with special conditions for steel components, e.g. in form of railing posts. Such items have to be grounded to the rebars used for the concrete. If the railing posts are made of galvanised steel and if the rebars are made of plain mild steel this implies a galvanic couple with a huge cathodic area at the moment when moisture enters the rebar web. In cases where the electrolyte contains de-icing salt it can cause rather rapid consumption of the protective zinc layer and consequently also rapid deterioration of the galvanised steel posts.

The Swedish Corrosion Institute, now KIMAB, together with the Swedish Rail Administration, the Swedish Road Administration and Zinc Info Norden AB, conducted a survey covering amongst others 10 road bridges crossing railroads where the railing posts were in electric contact with the rebars [3].

The inspections revealed that every single post on all 10 bridges had suffered galvanic corrosion, which was reported as severe for 7 bridges. All zinc had disappeared close to the concrete-air interface and “the steel was strongly attacked by red rust”.

The study also covered an exposure of stainless steel bars (grades 304L, 316L, LDX 2101 and 2205), to simulate stainless steel posts, and sacrificial anodes made of zinc. The stainless steel bars were exposed both coupled and uncoupled to the rebar web. It was found that all stainless steels were totally free from corrosion after one year of exposure and also that sacrificial anodes could be used to protect already attacked galvanised railing posts. The risk of getting galvanic corrosion on the rebar web due to the coupling to the more noble stainless steel railing was not investigated, but it can of course be neglected if the rebars are also made of stainless steel, as discussed below.

Solid stainless steel has during the last decade also become an option for the bridge itself. It should then preferably be made of duplex stainless steel to utilize the strength and the possibility to reduce gauge, weight and cost, Figure 11.

**Fig. 11** Bridges made of LDX 2101 (1), 2304 (2) and 2205 (3).



The test results suggest that the selection of 2205 can be justified if the design implies crevices or pockets out of access for natural cleaning by rainfall and if chlorides are present, e.g. from de-icing with chloride containing salts. If no de-icing with chloride containing salts and if pockets and crevices can be avoided at the design stage, a lower alloyed grade such as LDX 2101 or 2304 can be used also close to the sea.

**Fig. 12** Remnants of a concrete pier with mild steel rebars after 32 years (left) and a still intact pier with stainless steel rebars after 60 years (right).



### Tunnels

The most hostile conditions were found inside tunnels. The reason is presence of de-icing salt, brought into the tunnel by the heavy traffic load, in combination with lack of adequate cleaning.

Slightly acid conditions due to exhaust gas from the traffic has no major impact on the corrosivity of the environment inside a tunnel according to a previous study by Sandberg et al [4], which is indirectly confirmed by the similarities in result for the exposures inside the tunnel and under the Öresund bridge.

The previous study covered two years exposure in eight tunnels in the Stockholm area and the findings are not contradicted by the present investigation. The number of stainless steel grades was only three, 304, 316hMo and 2205, and stainless steel specimens were exposed in three tunnels only. However, existing stainless steel components in other tunnels were inspected and commented.

The study showed that without adequate cleaning the conditions will with time become uniform independent of height inside the tunnel while adjacent areas, e.g. service tunnels and escape routes possess less hostile conditions. It also showed that stainless steel items such as emergency telephone boxes, cabinets and fasteners made of 316hMo were free from corrosion. The latter result is, however, contradicted by the result from the extended tunnel exposure reported above, Figure 8. Similar items made of painted mild steel and zinc coated mild steel had suffered corrosion and had to be maintained.

A remark about a possible risk of stress corrosion cracking in 316hMo is contradicted by the results of the present study and considered irrelevant with reference to the test performed previously.

Also if the corrosion reported in table 4 is significant by definition, the rate is not high enough to cause any major harm to stainless steel components used in a tunnel, which also was confirmed by the experience from inspected stainless steel items. It is, however, advisably to use a kind of “belt and braces” philosophy for components critical for the safety inside a tunnel, i.e. to use higher alloyed grades than 316L and 316hMo.

The present study indicates that 2205 is a suitable grade for load bearing structures, important from safety point of view, which is in agreement with the previous report from the Swedish Corrosion Institute / KIMAB. In another work performed in the Mont Blanc tunnel, Böhni suggested the use of even higher alloy grades such as 254 SMO (S31254) [5]. The use of a high alloy grade such as 254 SMO, or a super duplex grade such as SAF 2507 (S32750), is justified if the conditions are more severe than in the Söderledstunnel, and if the application is critical from safety aspect.

#### Reinforcement bars.

Reinforcement bars have not been included in the studies reported above, but it is nevertheless a relevant issue considering the use of concrete for construction of bridges and tunnels and stainless steel being an excellent material for rebars. The steel grade is not critical since the high pH of the water penetrating into the rebars, the pore solution, prevents corrosion of stainless steel, but a high strength duplex grade such as LDX 2101 should be a cost effective option.

This was established by a comprehensive laboratory testing program reported at the annual NACE-conference in 2005 [6] and also clearly illustrated by practical service experience, Figure 12.

#### Classification

The classification normally used for construction materials is given in ISO 9223. This classification system is based on relative corrosion rates obtained on mild steel and zinc in different environments. Exposure results for the different environments, along with their ISO 9223 classifications, is given in Table 6. For iron and zinc, the most important corrosion mode is general, or uniform, corrosion, whereas for stainless steels, the dominating type of attack is localised corrosion. Given the differences in mechanism, it is not too surprising that the results in table 6 do not completely follow the aggressivity in the given classes. One example is the test on the Öland site, where comparatively high rates were obtained in spite of a C5 classification.

It would be rather easy to modify the environmental descriptions of the different corrosivity classes into application classes and use this concept for stainless steel and possibly other materials intended for use in road environments. The corrosion rates could be replaced by comments predicting a service life of minimum 50 years, which in turn are based on the test results reported in this paper. A modified version of EN ISO 12944-2, covering the stainless steel grades discussed above, is proposed in Table 7.

**Results at different locations with their respective ISO 9223 corrosivity classification. The designation p64/cc40 means pits detected up to 64 µm depth and crevice corrosion up to 40 µm depth.**

Table 6

Grade	Borås	Gothenburg	Öresund, road side	Öresund, underside	Öland	Stockholm tunnel	Höga Kusten	Svartnora
<b>Corrosivity class ISO 9223</b>	<b>C4</b>	<b>C4</b>	<b>C3</b>	<b>C2/C3</b>	<b>C5</b>	<b>C2/C5</b>	<b>C4/C5</b>	<b>C2</b>
4310	p64/cc40	p25/cc29	p33/cc64	p53/cc112	p28/cc100	p51/cc35	p42/cc80	cc29
4307	n.t.	n.t.	n.t.	cc48	n.t.	n.t.	n.t.	0
4404	0	p52	0	cc120	0	p52/cc172	p27	0
4436	0	0	0	n.t.	0	p60/cc65	0	0
254 SMO®	0	0	n.t.	n.t.	n.t.	0	n.t.	n.t.
LDX 2101®	0	0	0	0	0	n.t.	0	0
2304	0	0	0	cc40	0	n.t.	0	0
2205	0	0	0	0	0	0	0	0
SAF 2507®	0	0	n.t.	n.t.	n.t.	0	n.t.	n.t.
4372	n.t.	n.t.	cc65	cc138	cc75	n.t.	0	cc37

**Suggested application classes for stainless steels (SS) in road environments.**

Table 7

Class	Environment	Grade
SS1	Roads with low traffic intensity, regular cleaning, manual or by rainfall, or without de-icing.	All grades, but some staining for grades with PRE-numbers < 25.
SS2	Roads with high traffic intensity, frequent de-icing and regular cleaning.	All grades, but some staining also for grades with a PRE-number ~ 25.
SS3	Roads with de-icing but no cleaning, shielded from rainfall.	Grades with a PRE-number ~ 25 if some staining is acceptable. Grades with PRE ≥ 30 if no staining is acceptable.
SS4	Bridges	For roadside components, see SS1, SS2 or SS3. For the bridge itself, LDX 2101, 2304 or 2205.
SS5	Tunnels	All grades if no de-icing salt enters the tunnel or if some staining is acceptable and if cleaning is applied. Without cleaning, grades with PRE ≥ 25. Critical load bearing structures should be made of 2205, 254 SMO or SAF 2507. Special attention should also be paid to submarine tunnels where seawater may leak into the tunnel.

The classification in table 7 is based on the test results presented above. It can be used as a guide for steel grade selection as indicated below:

- SS1: Svartnora. All grades can be used, but some staining will occur on the low-alloyed grades.
- SS2: Borås, Gothenburg, Öresund roadside, Öland, Höga Kusten. As above, but risk of staining also on LDX 2101, 2304, 316L and 316hMo.
- SS3: Öresund underside. The grades listed above can be used, but grades with a higher corrosion resistance are required if staining can not be accepted.
- SS4: All bridges listed, i.e. the bridge itself at Svartnora, Öresund, Öland and Höga Kusten. A duplex stainless steel, but the selection of grade has to be based on a more detailed analysis of the local conditions.
- SS5: The Söderledstunnel in Stockholm. Grade depends on local conditions and requirements applied.

There is obviously no direct need to classify the bridge roadside locations, since they do not deviate from the general roadside conditions. Bridge conditions are, however, still slightly different when located close to the sea.

## Conclusions

1. The duplex grade 2205 has been fully resistant and can be used for all types of components along roads, in tunnels and on bridges, independent of location, e.g. for crash barriers, lamp posts, safety railing posts, electric fittings, load bearing structures etc. However, higher alloyed grades such as 254 SMO or SAF 2507 could be justified for critical safety components in tunnels with atmospheres more aggressive than those covered by the present studies.
2. The duplex grades LDX 2101 and 2304 can, just as the austenitic grade 316L, be used for all items, except critical load bearing structures, but the risk of superficial staining unless regularly washed must be considered, especially in a tunnel or other rain shielded location.

3. If the fabrication process requires the formability of an austenitic grade and if no staining is tolerated a grade of type S31726 (317LMN) or 904L (N08904) or 254 SMO should be used.
4. The grades 301 and 201 can be used for most items along roads unless the aesthetic appearance is important. They will suffer some superficial staining if airborne chlorides or de-icing salt are present.

## References

- [1.] Sederholm B. and Almqvist J., Classification of corrosivity in road environments – Two years field exposure of carbon steel, zinc, stainless steel, painted carbon steel and galvanized steel. Swedish Corrosion Institute report 2005:5, October 2005 (in Swedish).
- [2.] Forssander M., Korrosionskydd av belysningsstolpar och spänningsstolpar. Resultat från exponering upp till 11.5 år. Swedish Corrosion Institute report 2003:1, July 2005 (in Swedish).
- [3.] Sederholm B. and Almqvist J., Galvanic corrosion of railing posts on concrete bridges – Survey of damages and preventive measures. Swedish Corrosion Institute Report 2003:10E, December 2003.
- [4.] Sandberg B., Johansson T., Tuvevsson-Carlström L., Undersökning av tunnelmiljöns korrosiva egenskaper – Etapp 2. Swedish Corrosion Institute report 55 258, Stockholm August 2001 (in Swedish).
- [5.] Böhni H., Corrosion-resistant fastenings in road tunnels – Field tests. Structural Engineering International, No 4/92.
- [6.] Iversen A., Corrosion properties of UNS S32101 – a new duplex stainless steel with low nickel content tested for use as reinforcement in concrete. NACE Corrosion 2005, Paper No 05260, Houston, TX 2005.

*This paper is based on an original presentation from the Stainless Steel World conference in Maastricht, the Netherlands in November 2007.*

*Outokumpu is an international stainless steel company. Our vision is to be the undisputed number one in stainless, with success based on operational excellence. Customers in a wide range of industries use our stainless steel and services worldwide. We are dedicated to helping our customers gain competitive advantage.*

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