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Use of stainless steel rebars for reinforced concrete structures

Summary

Stainless steels exhibit a much higher corrosion resistance than ordinary black, galvanised or epoxy-coated rebars. Although the material costs are higher they may be used as an appropriate additional measure for the protection of concrete components with a high risk of corrosion. The suitability in a particular case may be judged on the basis of the life cycle costs. The world-wide increasing number of applications demonstrates impressively the effort of the building contractors, who, considering the widespread bad experiences, wish to avoid in the future premature failure and repair and to realise more durable and more economic concrete structures by the use of stainless steel rebars. This development goes along with a decreasing willingness of the building contractors to accept risks and with their increasing need, respectively, that the structures reach the requirements with a higher certainty than up to now.

The avoidance of extensive repair work saves in a sustainable way not only financial, but also material resources. Additionally, the risks of repairs in respect to their effectiveness and durability can also be avoided by the use of stainless steel rebars.

Under the name “stainless steels” a large group of steels are summarised, which exhibits a higher corrosion resistance than ordinary un- or low alloyed black steels. Stainless steels contain a chromium content over 10.5%, often nickel, molybdenum and nitrogen. Simultaneously, their carbon, sulphur and phosphorous content are reduced. They are divided in five classes with different microstructure and properties:

- austenitic stainless steels
- austenitic-ferritic stainless steels
- ferritic stainless steels
- martensitic stainless steels
- precipitation hardened stainless steels

Only stainless steels of the first three groups are commonly used as rebars for concrete structures.

There is no general answer to the question for what type of application, of concrete components or concrete structures, respectively, stainless steels may be considered as partial or complete replacement of ordinary rebars. Many influences and criteria can only be correctly evaluated for a specific case. Stainless steels may be used first of all because of the their good corrosion resistance and, therefore, especially for concrete components, which are exposed to chloride containing water or which should have a long life time and if their repair is difficult or costly.

The resistance of stainless steels against pitting or crevice corrosion is improved mainly by the elements chromium, molybdenum and nitrogen. The elements sulphur, manganese (especially in combination with sulphur) and carbon have a negative influence. The positively acting elements are summarised in the so called pitting resistance equivalent. The pitting resistance equivalent has no strict scientific meaning. Even though it is an useful guide for the evaluation

of the corrosion resistance of stainless steels (and nickel alloys) against pitting and crevice as well as against stress corrosion cracking.

Table Z.1 is a summary of the existing knowledge and experiences on the corrosion resistance and the possible applications of stainless steels in concrete. It is based on a very extensive literature survey and on contacts to various experts in different countries (see **Chapter 3**). The classification of the steels in corrosion resistance classes should give an overview and helps to choose the appropriate stainless steel quality for a specific application. As comparison, the ordinary, epoxy-coated and galvanised rebars have been included. A qualified and assured judgement of the long term behaviour of epoxy-coated rebars is extremely difficult. There is no international consensus (see **Chapter 3, 4.1, 4.3 and 4.7**). **Table Z.2** contents a list of actually available ripped stainless steel rebars.

The limits of the corrosion resistance classes have been set in a more conservative manner than the results of laboratory or field studies would have allowed. This approach should take the existing “stronger test condition” in a practical application into account. **Table Z.1** should not be “over-interpreted” since the initiation and rate of corrosion is affected by a large variety of factors (see **Chapter 4.4**). Additionally, the corrosion resistance may be negatively influenced by different steps of the processing and handling (e.g. cold working, heat treatment, welding, bending, see **Chapter 3 and 4.4**).

For middle to highly chloride burdened concrete components or structures, which should have a very long life time with no repair (70 to 100 years) or if their repair is very difficult to be carried out or very time consuming or costly, only CrNi- or CrNiMo-stainless steels with a pitting resistance equivalent WS >17 should be used. For such applications chromium steels are not recommended.

In cases, where high to very high chloride contents are to be expected, or if there are further unfavourable circumstances or corrosive influences combined with a high chloride content (e.g. water draining cracks, concrete cover less than 30 mm, porous or lightweight concrete, high temperature) or if there are unusual uncertainties in the execution of the concrete work, only CrNiMo-stainless steels with a WS >23 (resistance class 3) or even >31 (resistance class 4) should be used. This is also valid for especially important parts of the reinforcement, which should absolutely not corrode or if they ar very badly or not accessible for an assessment or repair.

It has to be pointed out, that because of the 475 ^{o}C-embrittlement, duplex stainless steels should not be used for concrete constructions with a high risk of fire and the possibility of a longer action of temperature >300 ^{o}C.

Since stainless steels are much more expensive than ordinary black rebars they should only be used in specially selected structural parts or as partial replacement of ordinary rebars. This leads to a mixed reinforcement and to the question of the compatibility of ordinary black and stainless steel rebars. As it has been described in **Chapter 4.5**, mixed reinforcement is allowed, for theoretical and practical reasons without special risks or restrictions. There is no higher corrosion risk than with concrete structures exclusively with ordinary black rebars.

In order to explore the actual state of the application of stainless steels for reinforced concrete structures in Switzerland an inquiry has been conducted in the second half of 1999 by the road administrations of the Swiss cantons and, additionally, by two Swiss federal administrations, seven road administration of Swiss cities and five railway companies as well as by some Swiss steel suppliers (see **Chapter 4.1**):

The results of this enquiry are as follows:

- Only three cantonal road administrations have used stainless steel rebars up to now.
- The vast majority of the cantons is convinced that other preventive measures (e.g. construction, concrete quality, concrete cover, surface treatment or designing as wear part – to be replaced easily –, better quality management) are more economic.
- A large majority of the cantons mentions the costs as the main obstacle for the use of stainless steel rebars.
- In the opinion of the cantons missing standards and guidelines as well as insufficient knowledge of the people involved in the building process are further important obstacles.
- Many cantons would appreciate a guideline on the use of stainless steels in concrete constructions as well as a more intense further education on this topic.

The extra costs of the application of stainless steel rebars (1.4003, 1.4462, 1.4571) for bridges and galleries (see **Chapter 4.1, 4.6 and annex**) realised in Switzerland were, according to the information of the road authorities of the cantons, between 0.4% and 8% of the total costs of the structures. The net material costs amounted from 4.80 to 19.50 sFr./kg. The portion of stainless steel rebars was between 0.6 and 7.5% of the whole reinforcement.

The Swiss as well as the foreign examples show that the construction costs might be higher when stainless steels are used. The additional costs depend on the type and the amount of the stainless steels used, but also on the type of application. Taking the life cycle costs as base for the choice of the material it ends up with conclusion that for exposed and endangered concrete structures the use of stainless steels may be very appropriate, i.e. economical. Structures and components with a higher durability exhibit clear advantages and reduce:

- the expenditure for the operation, maintenance, repair and replacement.
- the expenditure for the interruption of the operation (internal and external costs as for traffic jams, detours of the users and loss of production).
- the risks in respect of the effectiveness and durability which are very commonly related to repair work. This is especially true for components with a bad accessibility and which, therefore, can often not be repaired correctly (e.g. joints, the upper side of abutments).
- the work of the administrations and the owners (e.g. condition survey, assessment, planning, execution of repairs, monitoring of repaired structures).
- the environmental impact.

It is the conviction of many building contractors (and engineers), that the risk of chloride induced corrosion of the reinforcement of concrete structures heavily exposed to chloride containing water may be avoided with the common preventive measures (e.g. construction, concrete quality, concrete cover, surface treatment or designing as wear part, better quality management) and that they are more economical than the use of stainless steels. This conviction may be correct, but it needs to be verified by a sound calculation of the life cycle costs. It is partly in contradiction to the results of the modelling of the chloride ingress and corrosion process (s. **Chapter 1**).

Based on the actual experiences and knowledge one can conclude that – primarily because of economical reasons – stainless steel rebars will be used in the future not in less, but in a significant larger number of cases than up to now. This expected development makes it necessary to elaborate a SIA-guideline in which all aspects of the use of stainless steels in concrete construction are treated (corrosion, design, fatigue, bond, durability/steel quality, fire etc.). This would eliminate many of the present uncertainties and confusions. The present report as well as the English and American standard on stainless steel rebars represent a good base for such a guideline (see **Chapter 4.8**). Additional remarks in respect to action and research needed to be carried out are given in **Chapter 4.9**.

Table Z.1: Survey of the use of stainless steel rebars for concrete construction exposed to chloride containing environments and with a concrete cover of the reinforcement of about 30 mm, compared to other rebar materials. Possible stainless steel types: see **Table Z.2**.

BK: Corrosion resistance class

WS: Pitting resistance equivalent

Classification: + appropriate – inappropriate

Classification in parenthesis: classification uncertain

<u>Comment</u>:
The footnotes and the additional remarks in the Chapter 4.3 and 4.4 are to be considered!

Material of the reinforcement	WS 1)	BK	Carbonation of concrete					
			No	Yes	No	Yes	Yes 2)	Yes 2)
			Chloride content 3)					
			Zero	Zero	Low	Low	Mid	High
Ordinary black rebar	0	0	+	–	+/–	(–)	–	–
Epoxy-coated rebar	0	?	4)					
Galvanised rebar	0	0/1	+	+	(+)	–	–	–
Chromium-Steels 5)	10-16	1	+	+	+	(+/–)	(+/–)	–
Chromium-Nickel-Steels and Chromium-Nickel-Molybdenum-Steels	17-22	2	+	+	+	+	+	(+)
Chromium-Nickel-Molybdenum-Steels	23-30	3	+	+	+	+	+	+
Chromium-Nickel-Molybdenum-Steels	>31	4	For special cases e.g.: - Very high chloride content - High chloride content and further unfavourable circumstances					

1) WS: Pitting resistance equivalent calculated according to: WS = %Cr + 3.3%Mo + 0%N.
The minimum content of chromium and molybdenum according to EN 10088 and Stahlschlüssel (Germany) was used for the calculation. The nitrogen content was not taken into account.

2) The influence of the chloride content dominates. Carbonation is of minor importance since the rate of carbonation is low or the concrete cover is high.

3) <u>Chloride content</u>: low: $\leq$0.6 M.% in respect to cement content
middle: $\geq$0.6, but $\leq$1.5 M.% in respect to the cement content
high: $\geq$1.5, but $\leq$5 M.% in respect to the cement content
very high: >5 M.% in respect to cement content

4) The classification is uncertain/controversial. Comparative considerations and judgement: see **Chapter 4.7**.

5) The susceptibility to pitting corrosion of chromium steels with a low chromium content increases rapidly with decreasing pH. Depending on the concrete cover the carbonation of the concrete is, therefore, more or less important.

Table Z.2: Examples of available, ripped stainless steel rebars.
For the calculation of the pitting resistance equivalent WS: see **Table Z.1**.

Steel	**Designation**	**Cr,** M.%	**Mo,** M.%	**Pitting corrosion equivalent, WS**	**Corrosion resistance class**
Ferritic stainless steels					
1.4003	X2CrNi12/X2Cr11	10.5		11	1
Austenitic-ferritic duplex stainless steels					
1.4462	X2CrNiMoN 22-5-3	21.0	2.5	29	3
1.4501	X2CrNiMoCuWN 25-7-4	24.0	3.0	34	4
Austenitic stainless steels					
1.4301	X5CrNi 18-10	17.0		17	2
1.4306	X2CrNi 19-11	18.0		18	2
1.4311	X2CrNiN 18-10	17.0		17	2
1.4401	X5CrNiMo 17-12-2	16.5	2.0	23	3
1.4404	X2CrNiMo 17-12-2	16.5	2.0	23	3
1.4571	X6CrNiMoTi 17-12-2	16.5	2.0	23	3
1.4429	X2CrNiMoN 17-13-3	16.5	2.5	25	3
1.4529	X1CrNiMoCuN 25-20-7 / X1CrNiMoCuN 25-20-6	19.0	6.0	39	4

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