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Results of Laboratory and Field Investigations

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International Conference on Concrete in Marine Environments, Ed N. D. Anh and M. W Braestrup, IABSE Vietnam National Center for Natural Science and Technology, Hanoi, Vietnam (2002), p 193-202

STAINLESS STEEL REINFORCEMENTS IN CONCRETE STRUCTURES

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ABSTRACT

The use of stainless steel reinforcements is a protection method for chloride contaminated structures. The present contribution shows a practical method to characterize and compare the corrosion behaviour of reinforcement steels. Two stainless steels and an ordinary carbon steel (reference) were investigated. The results of the investigations show the influence of the chloride content, the pH value and the surface quality on the corrosion resistance.

1. INTRODUCTION

Chlorides from deicing salts or sea water and carbonation cause corrosion of rebars, which are normally well protected by the alkalinity of concrete. Outcomes of actual research show that a time of more than 50 years will not be achieved without corrosion on the rebars, even with dense concrete and covers of more than 40 mm [1, 2]. In the last few years several protection methods were proposed to extend initiation time and to lower the repair costs. The use of stainless steels is a suitable method to increase the corrosion resistance of rebars. Stainless steels have a high chromium content of more than 10.5% and contain additional elements like Nickel or Molybdenum. These steels have a higher corrosion resistance than galvanised rebars and are not sensitive to defects contrary to epoxy coated rebars. Stainless rebars are used in Switzerland seldom due to high costs compared to ordinary carbon steels. To lower the initial material costs during construction there is an actual intent to optimize the alloy content and the manufacturing process of the steels without risking the longterm durability of the concrete structure. The suitability of such steels for practical applications should be carefully investigated first. Examples of such research are given in [3, 4].

2. INVESTIGATIONS

2.1 Tested steels

A chromium steel TOP12 (X2Cr12, basis 1.4003), developed by von Moos Stahl AG, a duplex stainless steel (X2CrNiMoN22-5-3, 1.4462) and an ordinary carbon steel (S500) were investigated. The rebars had a diameter of 10 mm and 16 mm. TOP12 is manufactured by a new patented production process. The material properties are achieved by only two production steps: hot rolling of the billets in several steps to the final product and controlled cooling [5]. The chemical composition of the investigated steels is given in table 1.

Table 1. Chemical composition of investigated steels (mass-%)

	S500	TOP12	1.4462
C max.	0.15	0.03	0.03
Mn max.	0.59	1.50	2.00
S max.	0.43	≤0.015	≤0.015
Cr min./max.	0.09	10.50/12.50	21.00/23.00
Ni min./max.	0.12	0.30/1.00	4.50/6.50
Mo min./max.	0.02		2.50/3.50
N min./max.		0.030 (max.)	0.10/0.22

2.2 Solution tests

A synthetic pore solution of pH 13.5 was used for solution tests (table 2). To perform experiments at low pH the pore solution was carbonised by flooding with CO₂. The intended chloride content was achieved by addition of NaCl.

Table 2. Composition of synthetic pore solution

components	Ca(OH) ₂	NaOH	Na ₂ SO ₄	KOH
amount [g/l]	0.0096	0.6168	3.1220	12.1759

Potentiodynamic current potential curves (propagation rate 0.2 mV/sec) were performed to characterize the corrosion behaviour of steel samples in synthetic pore solution. The pitting potential was used as criteria to determine corrosion initiation. A standard corrosion test cell was used for tests on the cross section of the rebars. A special cell with flexible sealings was constructed to perform experiments on the rolling skin of ribbed rebars. For rebars with a diameter of 10 mm the surface exposed to the electrolyte was 23 cm², for

rebars \varnothing 16 mm 35 cm². The samples were polarized cathodically 5 minutes in advance at a potential of -600 mV_{SCE}.

- chloride content: 0/0.3/0.5/1/2/3/5 mol/l
- pH-value: **13.5**/12.5/11.8/**10.5**/9.5/8.0
- surface quality: grinded (320 grid)/sandblasted/as received

2.3 Suction tests with mortar blocks

Two rebars and two chloride sensors were fixed in mortar blocks (max. grain size 4 mm, w/c 0.6) to determine the critical chloride concentration in the pore solution (Fig. 1). The sensors were situated at the same level as the lower end of the rebars. Concentration of free chlorides could be determined by a potential measurement [6]. After a preliminary saturation time in water the mortar blocks were immersed in a NaCl solution. The blocks were ventilated on the top side to obtain a slow and continuous uptake of the salt solution. Data acquisition (corrosion potentials and potential of chloride sensors) was performed by a data logger continuously.

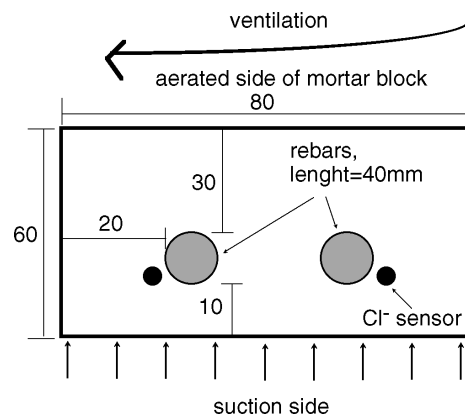


Fig. 1 Instrumented mortar blocks for suction tests

2.4 Field tests

Field tests were performed in the gallery Cianca Presella situated at the Swiss national highway A13 in the Canton of Grisons. A concrete block (concrete max. grain size 16 mm, w/c 0.6) with dimension 100 x 30 x 20 cm was made in the laboratory and deposited in the splash zone between two columns of the gallery. Samples of ordinary carbon steel, TOP12 and duplex steel, chloride and temperature sensors were fixed in the concrete block in a depth of 10

mm. At the backside of the block a reinforcement mat was fixed as a cathode. Data acquisition was performed continuously by a data logger which was developed specifically for the online-monitoring of concrete structures [2].

3. RESULTS AND DISCUSSION

3.1 Solution tests

The pitting potentials at different pH values of TOP12 are shown in Fig. 2. The tests were performed on a grinded surface. The pitting potentials decrease at all chloride concentrations when the pH is lowered. The pitting potential decreases 150 to 200 mV (average) even at a reduction of pH value from 13.5 to 12.5. Further reduction results in an additional but less significant decrease of the pitting potential. To test the influence of surface quality on the corrosion resistance the rolling skin of TOP12 steel has been removed by sandblasting. Pitting potentials increase significantly by this treatment at pH 13.5 (Fig. 3). At pH 10.5 (corresponds to carbonised concrete) no significant effect of sand blasting on corrosion resistance could be detected. Samples are active at open circuit potential, even at low chloride concentrations, not only with but also without rolling skin. A negative effect on corrosion behaviour by the rolling skin was also stated in [7].

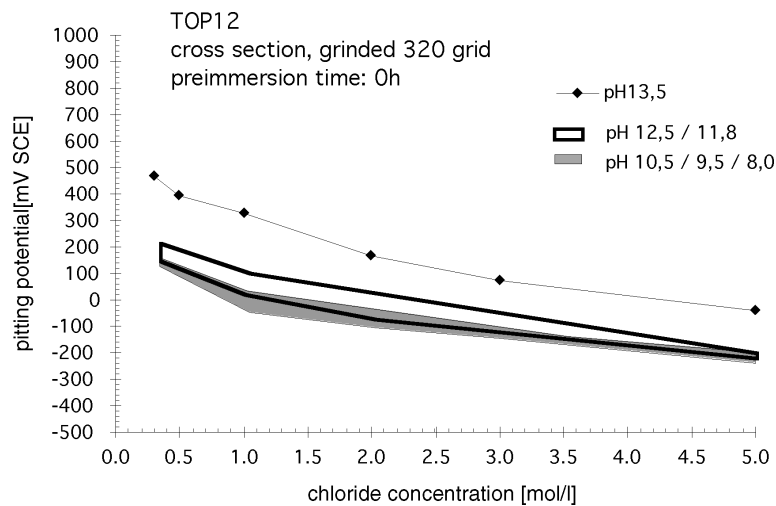


Fig. 2 Pitting potentials of TOP12 as a function of pH. Measures were taken on grinded cross section (grid 320)

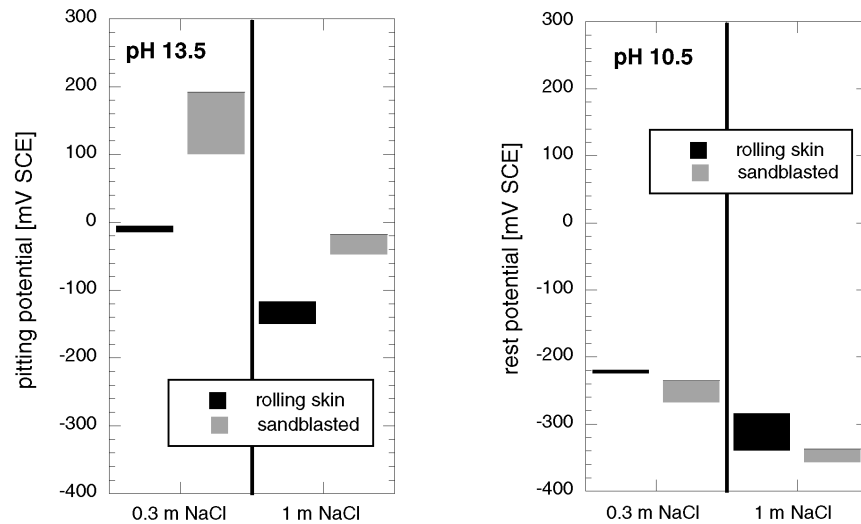


Fig. 3 Comparison of pitting potentials on TOP12 samples. Measures were taken on rolling skin and on sandblasted surface.

An overview on pitting potentials of non treated samples (not sandblasted) of ordinary carbon steel, TOP12 and duplex steel at pH 13.5 and 10.5 is given in Fig. 4. TOP12 is more resistant as ordinary carbon steel at pH 13.5. It is to mention that the change of the curve is slow within this potential range. This makes it more difficult to determine the critical chloride concentration for pitting. Resistivity of duplex steel is significantly better than of the two other investigated steels. Only at chloride concentrations above 3 mol/l pitting occurs. At pH 10.5 there is almost no difference in corrosion behaviour between ordinary carbon steel and TOP12 steel. Duplex steel is resistant up to a chloride concentration of about 1 mol/l at this pH.

Charge transfer resistance of the cathodic reduction reaction

Beside the determination of pitting potentials also current potential curves in cathodic direction were measured to get informations on charge transfer resistance of the cathodic reduction reaction in case of macro cell corrosion. Cathodic current potential curves of ordinary carbon steel, TOP12 and duplex steel are shown in Fig. 5. Tests were performed on rebars with rolling skin. At a potential range between -300 and -600 mV_{SCE} TOP12 shows the highest cathodic current density. The cathodic reaction of duplex steel which has no rolling skin is inhibited the most. The higher charge transfer resistance

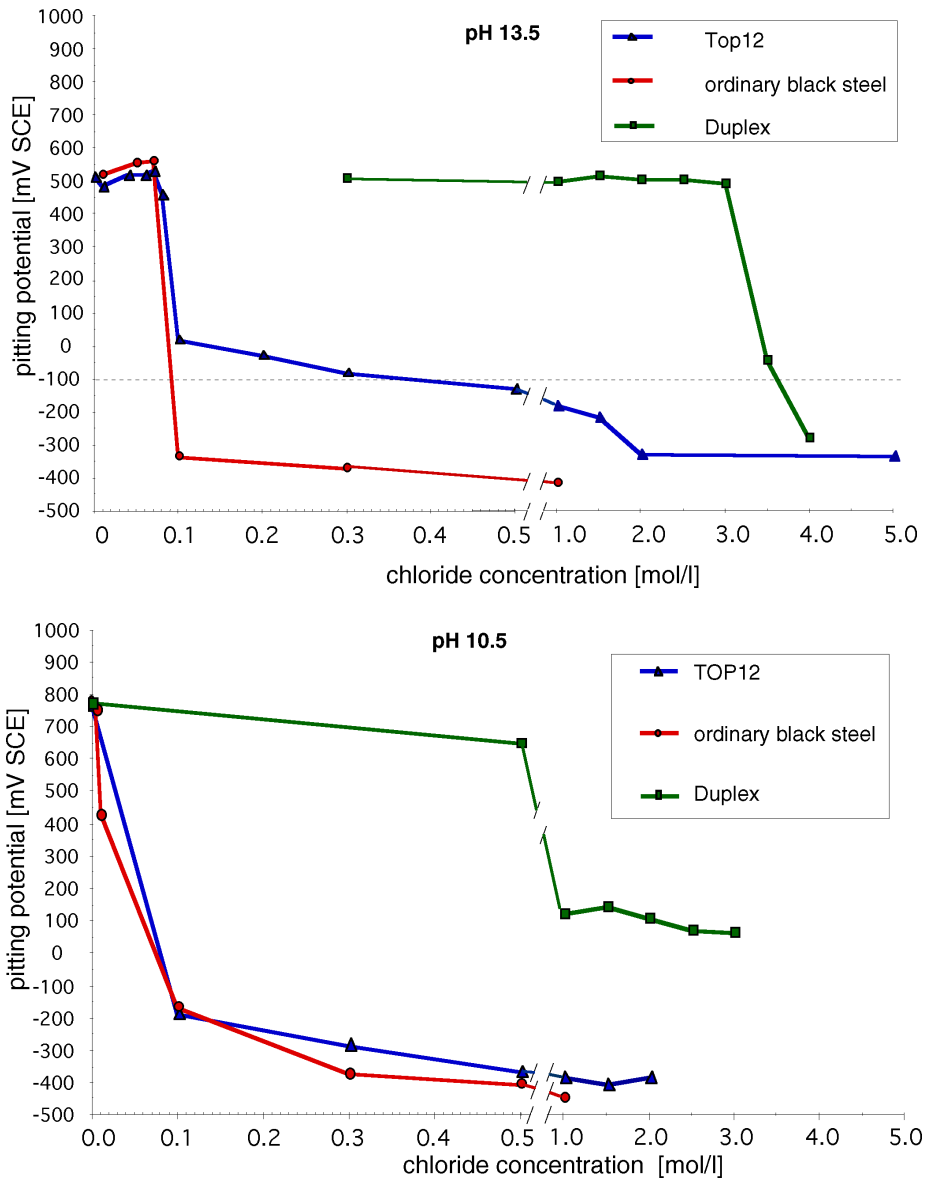


Fig. 4 Pitting potentials of ordinary carbon steel, TOP12 and duplex steel at pH 13.5 and 10.5. Measures are made on the rolling skin.

of the cathodic reduction reaction of stainless steel compared to ordinary carbon steel was also identified by other research projects [8].

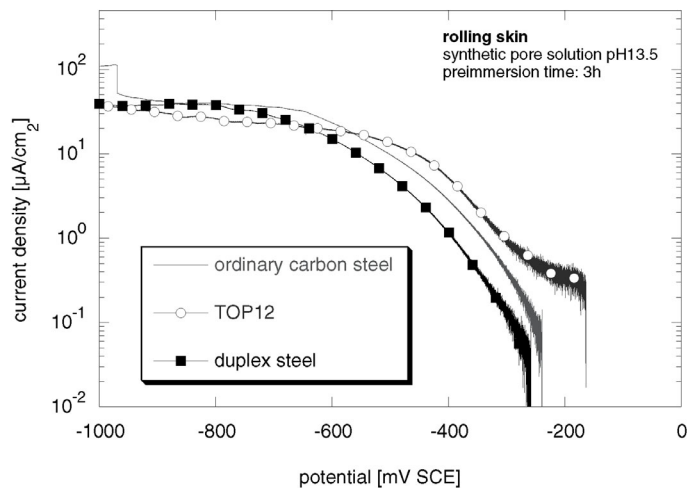


Fig. 5 Cathodic current potential curves of ordinary carbon steel, TOP12 and duplex steel. Tests were performed on steels with rolling skin.

3.2 Suction tests with mortar blocks

Examples of results of suction tests are shown in Fig. 6. As soon as the chloride concentration reaches a critical value, a strong potential drop occurs which indicates the corrosion initiation. A summary of critical chloride con-

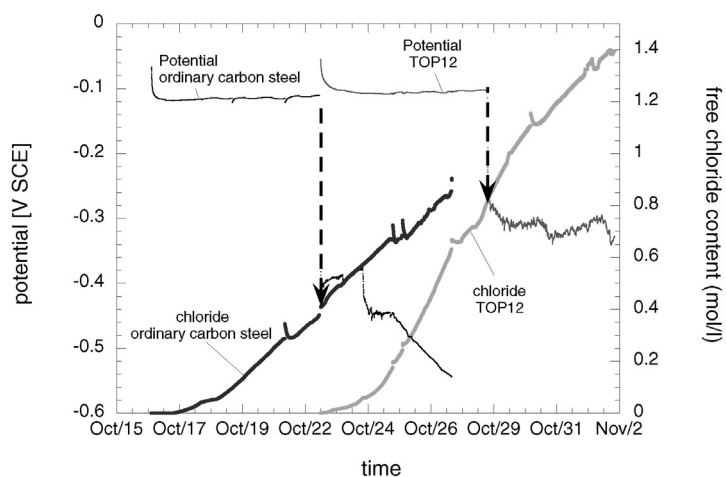


Fig. 6 Corrosion potentials over time of ordinary carbon steel and TOP12 and increase of chloride concentrations in the pore solution.

tents for pitting corrosion obtained by suction tests is given in Fig. 7. The critical chloride concentration of the TOP12 with rolling skin is 2 to 3 times higher than for ordinary carbon steel. Critical chloride contents for sandblasted TOP12 samples are significantly higher (>3 mol/l) than for samples with rolling skin. This confirms the results obtained by solution tests. Duplex steel could not be activated in suction tests. The critical chloride concentration is higher than 5 mol/l.

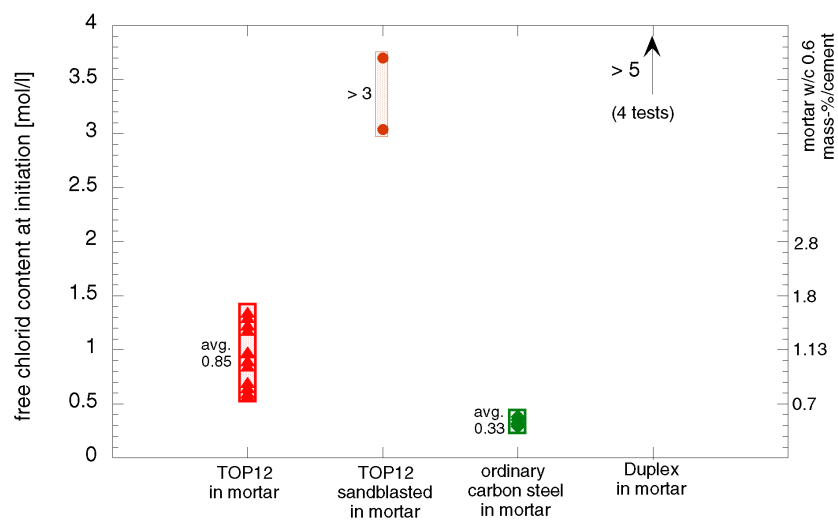


Fig. 7 Critical chloride content in mortar for ordinary carbon steel, TOP12 and duplex steel.

3.3 Field tests

Results of field tests are shown in Fig. 8. The field tests were started in October 2000. The development of the corrosion potentials show corrosion initiation in the first half of 2001 on ordinary black steel samples. The critical chloride concentration determined by chloride sensors was around 0.4 mol/l. The activation of rebars could clearly be detected by the potential measurements. Many activation and repassivation processes occurred with the TOP12. The first stable initiation process after 9 months on TOP12 samples occurred at a chloride concentration of about 0.8 to 0.9 mol/l, which confirms the results obtained in laboratory tests. The potential of duplex steel over time is practically constant. All samples were passive up to the maximum chloride concentration of 1 mol/l reached in field tests so far.

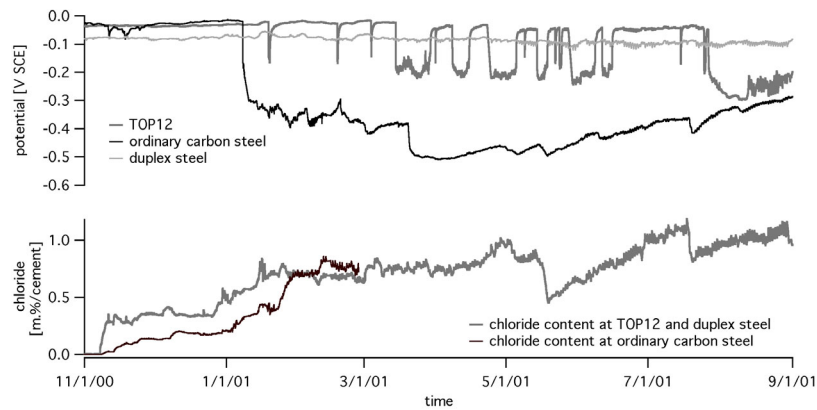


Fig. 8 Corrosion potentials for ordinary carbon steel, TOP12 and duplex steel. Development of chloride concentration in the Gallery Cianca Presella, Swiss national highway A13.

4. CONCLUSIONS

- The results of the corrosion tests of a chromium steel (TOP12), a duplex steel and an ordinary carbon steel as reference showed a good agreement between solution test, suction test (mortar blocks) and field tests. The combination of the different test methods is well suitable to characterize the corrosion resistance of reinforcement steels.
- Critical chloride content for pitting corrosion of chromium steel TOP12 is between 0.7 and 1 mol/l in alkaline concrete at pH 13.5. This is about 2 to 3 times higher as for ordinary carbon steel (0.25 to 0.4 mol/l). Duplex steel is resistant up to a chloride concentration of at least 3 mol/l.
- Corrosion resistance of all tested steels depends strongly on pH value. In carbonized concrete or concrete with lower alkalinity there is almost no difference in corrosion behaviour of TOP12 and ordinary carbon steel.
- Sandblasting of TOP12 increases the corrosion resistance compared to samples with rolling skin. Due to rolling skin charge transfer resistance of the cathodic reduction reaction is also reduced.
- Due to the good agreement between the results of the laboratory and field tests further optimizations in the manufacturing process (e.g. surface treatment) of the investigated steels can be tested with selected solution tests very briefly.

Possible practical applications of the steels are summarized in table 3.

Table 3. Practical application of ordinary black steel, TOP12 and duplex steel

ordinary black rebar	TOP12 with rolling skin	TOP12 without rolling skin	duplex steel
<i>no corrosion risk</i>			
+	+	+	+
<i>carbonised concrete, cement with low alkalinity</i>			
-	+	+	+
<i>corrosion induced by chlorides (m.%/cement)</i>			
+ (max. 0.4%)	+ (max. 1.0 %)	+ (up to about 3.0%)	+ (up to about 5.0%)
<i>corrosion induced by chlorides (m.%/cement) and reduced pH</i>			
-	-	-	+ (bis ca. 3.0%)

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