



Dept. 3 Building protection, chemistry, environment  
Div.34 Corrosion, corrosion protection, electrochemistry and material science

## TEST REPORT

### assessment

Applicant: Hilti Corporation  
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Principality of Liechtenstein

Subject: **Corrosion behaviour of the X-CR nail**

Test report date: May 26, 1994

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Pages of text: 9

Appendices -

## RESISTANCE TO CORROSION OF X-CR NAIL

### 1. Order

An assessment had to be made of the corrosion resistance of nails which are used for powder-actuated fastening. To this end, laboratory tests were carried out and rated to determine the susceptibility to pitting of the nail material and the finished product (nail) in comparison with the usual grades of stainless steels used in the field of fastenings.

The applicant intends to apply for approval of the X-CR nail by a construction supervisory authority.

### 2. Subject

The X-CR nail is manufactured from austenitic chromium-nickel steel (X-CR, cold drawn wire) and is used in combination with a washer which is also manufactured from stainless steel (316L grade). For specific application conditions, this nail is subjected to a heat treatment consisting of 10 minutes tempering at 490°C, and in special cases it is subsequently zinc plated.

#### 2.1 Field of application/exposure to corrosive conditions

This nail is used for a variety of fastenings in the construction industry. This permits the assumption to be made that it is subjected primarily to corrosive atmospheric conditions in conjunction with exposure to chemicals from building materials, above all from concrete, but contact with other metals i.e. unalloyed steel, galvanised steel, aluminium alloys etc., must be taken into consideration.

### 3. Corrosion behaviour of stainless steels

The formation of a sub-microscopic passivating layer gives stainless steels their resistance to corrosion. A prerequisite is that the steel contains at least 12% chromium. This passivity is effective for the entire pH range of the corrosive mediums which can be assumed to be encountered here i.e. from solutions of "acid" gases, such as nitric oxides and sulphur dioxide, to the alkaline electrolytes in concrete. Uniform corrosion can thus be excluded for all the stainless steels related to the subject-matter being discussed here. On the other hand, consideration must be given to local corrosion i.e. pitting and crevice corrosion, which will be looked at in greater detail in the following.

#### 3.1 Pitting, crevice corrosion and galvanic corrosion

A local attack of corrosion i.e. pitting and crevice corrosion, can be triggered by halides e.g. chloride, bromide and iodide, on stainless steels. It is sufficient to regard chloride as the initiator where corrosion in field practice is concerned. Chlorides occur in large amounts as constituents of sea water and road salt (deicing salt). Pitting and crevice corrosion are related in their mechanisms of corrosion: the initial process takes the form of a local break-down of the passivating layer after a certain "incubation" period (up to several years in the case of atmospheric corrosive conditions).

Afterwards the metal dissolves during which a very acid electrolyte rich in chlorides forms in the hole or crevice. The corrosion then progresses assisted by differential aeration cells where the passive surface in the vicinity of the point of corrosion acts as a cathode i.e. an oxygen uptake area. Under circumstances, holes can "repassivate" and stop growing. This takes place in particular with austenitic CrNi steels containing molybdenum.

Whether or not pitting takes place is governed by whether or not a critical threshold of electrode potential is exceeded. This is called the pitting potential and it depends on the chemical constituents, especially on the content of chromium, molybdenum and nitrogen, on the grain structure, of greatest interest here is "deformation induced martensite" and  $\delta$ -ferrite, and on the quality of the surface. It can be determined during a test. Owing to the comparable mechanisms, it can also apply as a measure of susceptibility to crevice corrosion. Where the chemical constituents are concerned, the susceptibility to pitting can be estimated on the basis of the alloying elements i.e.  $T = \% \text{ Cr by weight} + 3.3 \% \text{ Mo by weight}$ .

Where stainless steels are concerned, there need hardly be any second thoughts about the effects of conducting metal contact with other metals because stainless steels are higher in the galvanic series i.e. nobler, than most generally used materials, such as aluminium, zinc and steel, because of their passivity. As a result, they enjoy cathodic protection through their contact with these metals. Consequently, this contact generally has a favourable effect on the corrosion behaviour of stainless steels.

#### 4. Pitting studies

In view of the fact that susceptibility to local corrosion depends decisively on the surface quality, the grain structure i.e. heat treatment and cold forming, apart from on the ratio of alloying constituents, reliable statements about resistance can only be made after carrying out tests.

Statements about resistance are made meaningfully either in the form of comparison (screening) tests, where the comparison is made using materials with which many years of experience already exists, or the test is conducted under the worst conditions in the medium which will probably be acting. In the case of pitting or crevice corrosion, it is then sufficient to determine the pitting potential, which can be ascertained during a laboratory test. (Crevice corrosion, as mentioned, is related to pitting where the mechanisms are concerned, but it cannot be reproduced so well during a test.)

The tests described on the following pages were arranged as comparison (screening) tests during which X-CR material in the form of a drawn wire as well as the final product (nail) was tested in comparison with widely used austenitic chromium-nickel steels (AISI 304 and AISI 316). The medium selected was synthetic sea water as per ASTM D 1141 and the testing method was the 24-hour potentiostatic test at room temperature.

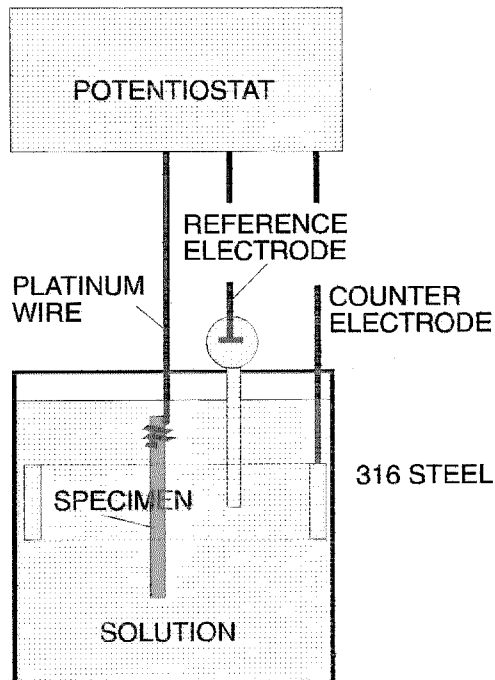


Fig. 1: Test arrangement for determination of pitting potential (potentiostatic tests)

#### 4. Specimen material

Drawn wires (X-CR, 316, 304) and rods (316L) were used as the specimen materials and, in addition to these, heat-treated as well as non-heat-treated nails. Some of the nails were driven into concrete prior to the test to ensure that they had a surface very similar to that in practice. Nails equipped with washers and nails without washers were tested.

##### 4.1 Chemical composition

Analyses of the X-CR steel and comparison materials are given in table 1 together with nominal values according to the steel-iron list (Stahl-Eisen-Liste). Analyses of the comparison materials complied with the nominal values.

Element	X-CR	316 L (actual)	316 L (nominal)	304 (actual)	304 (nominal)
C	0.013	0.023	≤0.03	0.037	≤0.07
Si	0.39	0.41	≤1.0	0.52	≤1.0
Mn	3.5	1.5	≤2.0	1.5	≤2.0
P	<0.01	<0.01	≤0.045	<0.01	≤0.045
S	0.0045	0.011	≤0.025	0.023	≤0.030
Cr	22.0	17.5	17/18.5	18.6	17/19
Ni	15.6	12.7	12.5/15	9.0	8.5/10.5
Mo	2.2	2.7	2.5/3	0.4	

Table 1: Chemical analysis of specimen materials

#### 4.2 Surface/grain structure

Figs. 2 to 4 are scanning electron microscope photos of the surface of the specimen material used (wire or rod, 4 mm in diameter).

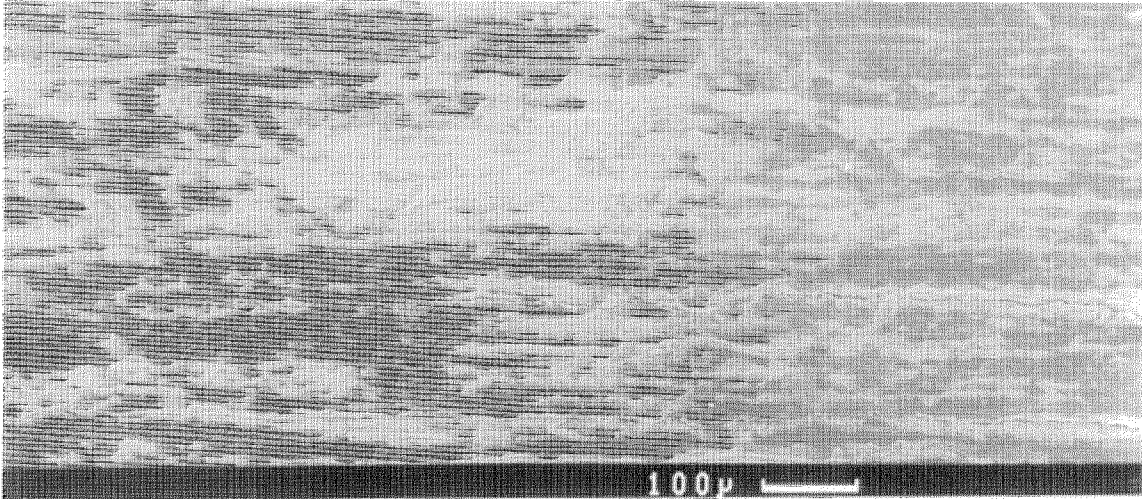


Fig. 2: Surface of X-CR wire (scanning electron microscope photo) showing clear die marks

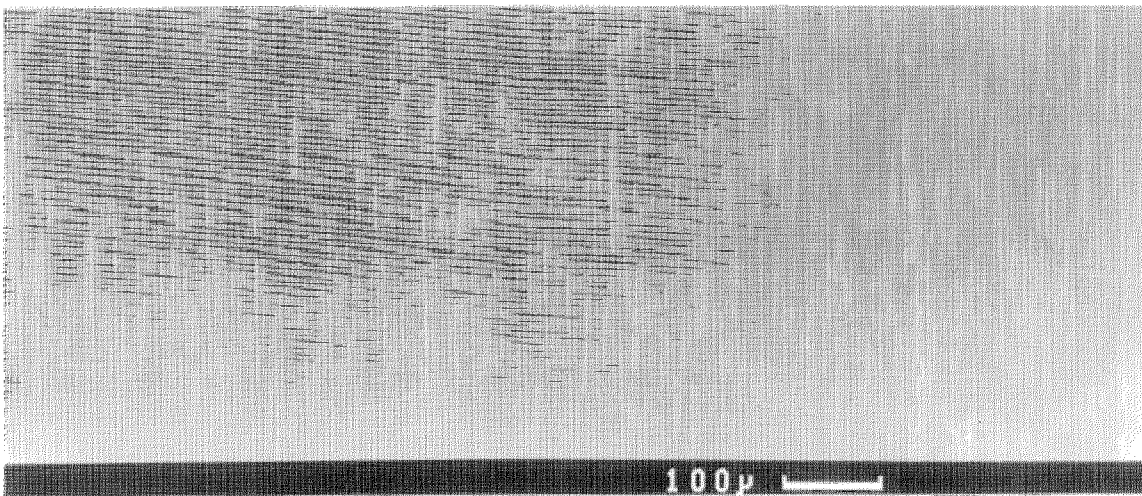


Fig. 3: Surface of specimens of 316L material (scanning electron microscope photo) showing signs of machining in a circumferential direction

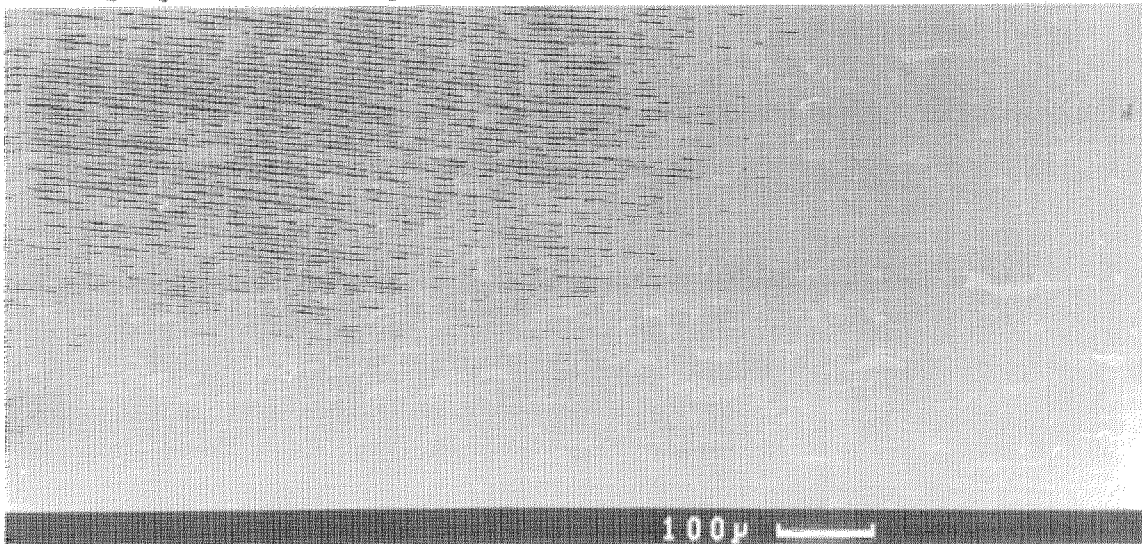


Fig. 4: Surface of samples of 304 material (scanning electron microscope photo) showing die marks

The (austenitic) grain structure of the three specimen materials is shown in figs. 5 to 8 (etched micro-sections). The drawn X-CR wire has a very pronounced texture.

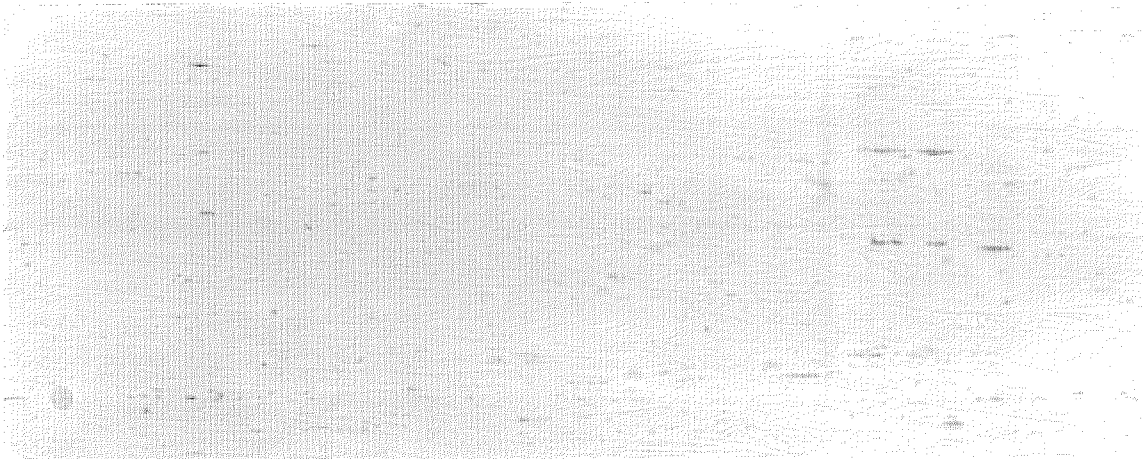


Fig. 5: Micro-sections (etched) of X-CR specimen material; longitudinal micro-section (200 x magnification)



Fig. 6: Micro-section (etched) of 316L specimen material; longitudinal micro-section (200 x magnification)

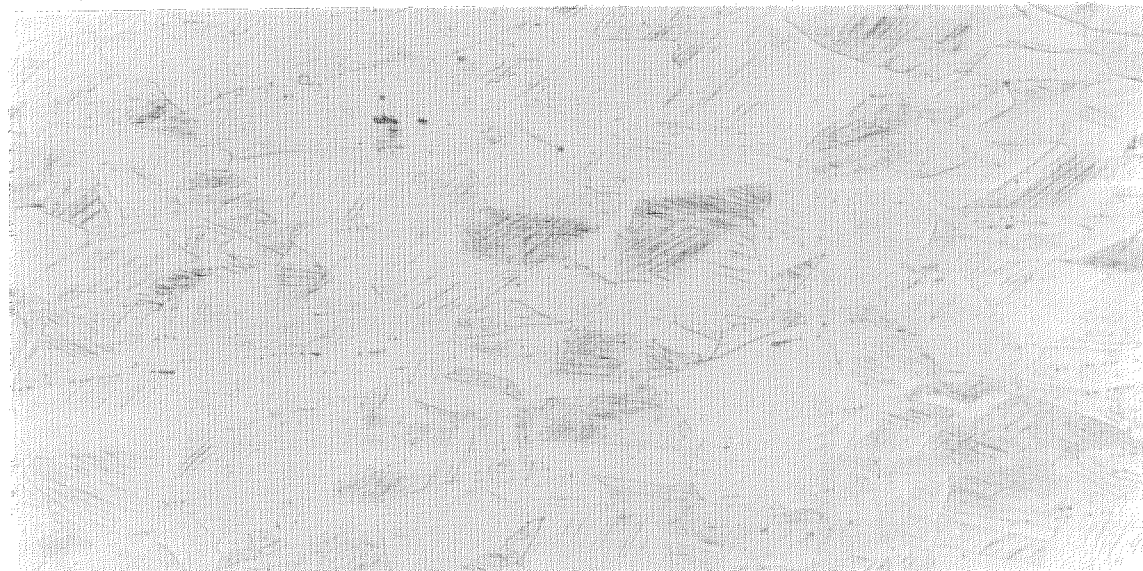


Fig. 7: Micro-section (etched) of 304 specimen material; longitudinal micro-section (200 x magnification)

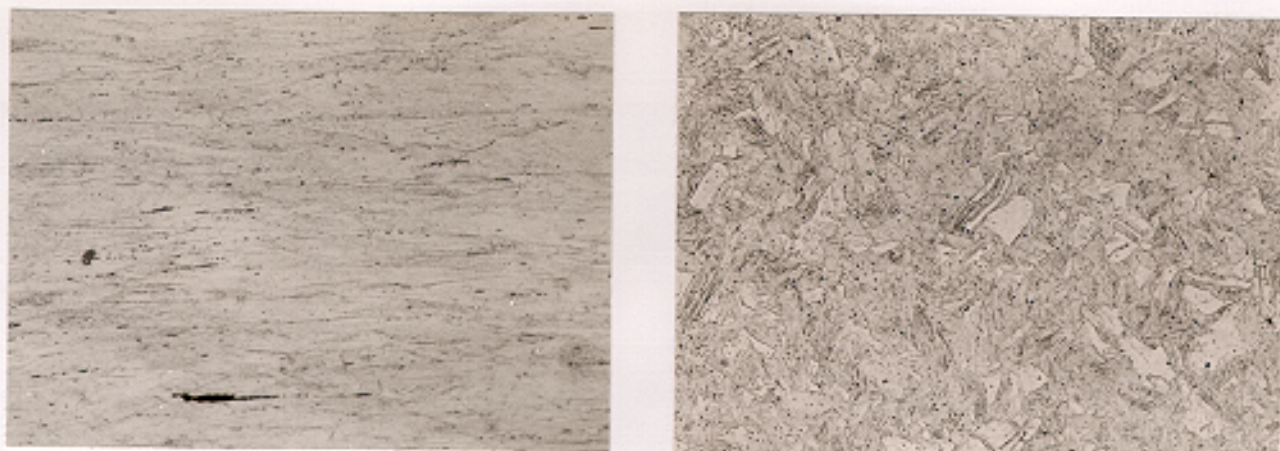


Fig. 8: Micro-sections (etched) of X-CR specimen material tempered for 10 min. at 490°C; left: longitudinal micro-section; right: transverse micro-section (200 x magnification)

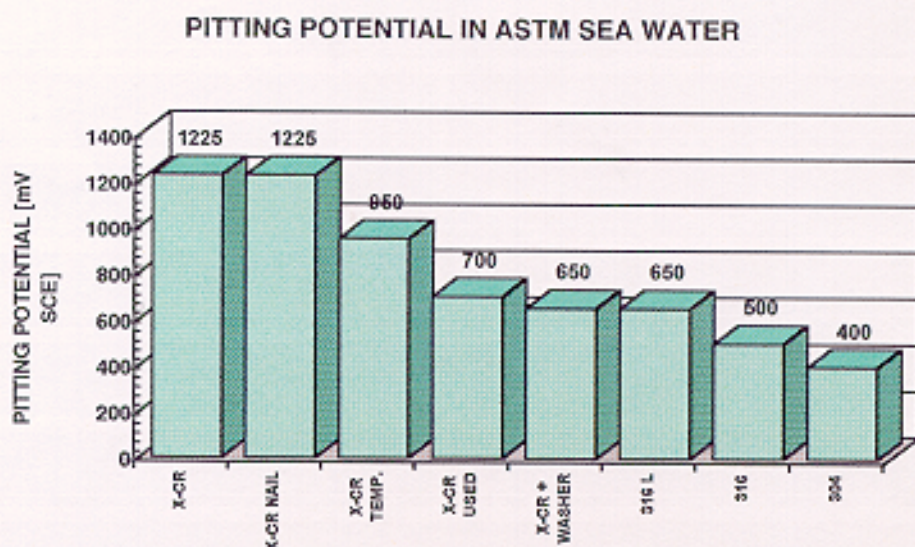
## 5. Critical pitting potential

### 5.1 Open-circuit (zero-current) potential

The following open-circuit (zero-current) potentials were measured in standing sea water (open and exposed to the air) after 24 hours.

Material/o.c. potential	X-CR without washer	X-CR with washer	Washer of 316L	316	304
(mV (SCE))	-177	-100	-76	-146	-143

Table 2: Open-circuit (zero-current) potentials in sea water



\*) corrosion on washer only

Fig. 9: Pitting potentials determined for rods and nails (potentiostatic tests over 24 hours, potential increment: 25 mV beginning at open-circuit potential)

Fig. 9 shows the results of the potentiostatic tests carried out with rods and nails in synthetic sea water.

The breakdown potential of the X-CR wire material, as also of undamaged nails without a washer, is at very positive values of 1225 mV and is thus clearly higher than the values of the ordinary AISI 316 and AISI 304 grades of steel. If the nails are tested with washers, the latter always fail and thus determine the breakdown potential which corresponds well with that measured for 316L material.

The corrosive attack of a nail always begins at the point. Pits appear in the head section and finally in the shank only at higher potential values .

Tempered material (nails tempered for 10 min. at 490°C) shows a loss of resistance to corrosion (fig. 11). The breakdown potential is still clearly higher, at 950 mV, than that of comparison materials (AISI 304 and 316). Here too, corrosion begins at the point of the nail, occurring on the head and shank only at much higher potentials, these being:

- o at about 1000 mV on the head and
- o at about 1150 mV on the shank.

The results obtained with wire material are shown again in fig. 10 with the alloy index calculated from the analysis values.

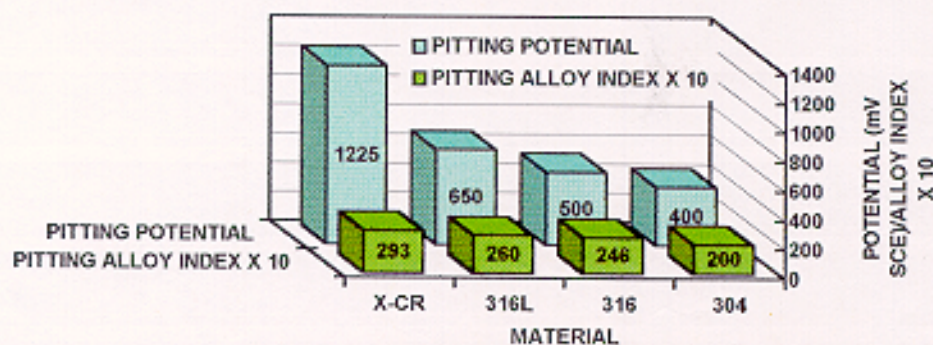


Fig. 10: Pitting potential and alloy index of tested materials

Roughly, the determined breakdown potentials correlate with the alloy index. Apparently, there is no decisive influence of surface changes due to drawing and cold forming on the resistance ratings of these high-quality grades.

## 5. Ratings/assessment

X-CR material is clearly superior to widely used austenitic CrNi steels of the grades AISI 304 and 316 where the resistance to uniform and localized eroding corrosion is concerned. This also applies to the heavily cold-formed and, according to given information, heat-treated final product (nails).

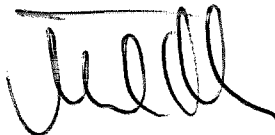


Since experience from field practice and weathering tests lasting many years with AISI 304 and 316 steels [1 - 4] is available, which already testifies to the adequate resistance of these steel grades, especially AISI 316 steels containing molybdenum, for use "in very corrosive conditions in industrial and marine air" ([4] regarding 316 material: results from weathering tests lasting 10 years), this resistance exists for the X-CR nail with far greater certainty.

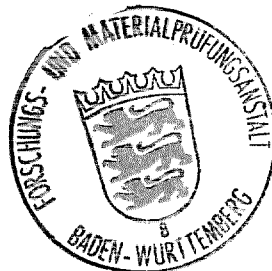
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2. G. Witte: Techn. Mitt. Krupp Werksberichte 31 (1973) [*Technical Bulletin, Krupp plant report 31 (1973)*]
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4. R. Ergang, M.B. Rockel: Werkstoffe und Korrosion 26 (1975) [*Materials and corrosion 26 (1975)*]

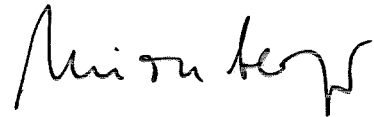
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