HYDROGEN INDUCED STRESS CORROSION OF PRESTRESSING STEELS - INTRODUCING A NEW TESTING METHOD

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SUMMARY

The causes for the susceptibility of prestressing steels to hydrogen induced stress corrosion and the failure mechanisms occurring could be researched in depth. In contrast to this an exact testing method on the evidence of the prestressing steel sensitivity valid for all steel types does not exist. This has caused not only prejudices against prestressed buildings but has also led to additional safety precautions in practice (so-called robustness reinforcement). Economic disadvantages are the result. Therefore, the development of an accepted, meaningful and quickly performed test and inspection method is the aim of the co-operation research between the Leipzig University "Institut für Massivbau und Baustofftechnologie (IMB)" and the "Institut für Werkstofftechnik und Werkstoffprüfung (IWW)" of the Otto-von-Guericke University in Magdeburg. The measuring of electrochemical noise (ECR) for the investigation of the sensitivity of prestressing steels to hydrogen induced stress corrosion is a promising method. It can be used both for early diagnosis of corrosion processes under laboratory conditions and for practical corrosion monitoring.

Keywords: Durability of prestressed concrete structures, protection from hydrogen induced stress corrosion

1 INTRODUCTION

Damage to constructions of prestressed concrete cause doubts about their durability again and again. In particular the not completely answered questions on the susceptibility of prestressing steels to hydrogen induced stress corrosion are responsible for these doubts.

For testing the sensitivity of different types of prestressing steel (above all dependent on the preloading factor) no suitable method exists, which allows a detailed evaluation in an acceptable period of time. With the well known testing method established by the Deutsches Institut für Bautechnik prestressing steels are analysed in a neutral solution (a pH index of 7) containing 0,052 mol/l sulphate, 0,014 mol/l chloride, and 0,017 mol/l rhodanide at a temperature of 50°C. The prestressing steels are insensitive if they can be loaded continuously for more than 2000 hours at 80 % of their tensile strength. However, the different structure properties of the prestressing steel types and the

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different surface conditions caused by the manufacturing process substantially influence the susceptibility of the prestressing steels to hydrogen stress corrosion. Varying sustained load lives are the result. For this reason and above all with respect to the insufficient measuring and characterizing of the ongoing processes during sustained load tests (for example the formation of corrosion pits, incipient cracks etc.) the demand for a new testing method is urgently necessary. Furthermore, there are only a few investigating methods which treat the sensitivity of prestressing steels to hydrogen stress corrosion in dependence on preloading.

In a current research project supported by an industrial consortium, on the one hand the service life of prestressed concrete components is to be investigated, and on the other hand a new testing method is to developed. The new testing method will be based on the aspect of electrochemical noise. This method will facilitate the exact evaluation of the sensitivity of prestressing steels to hydrogen induced stress corrosion.

2 INVENSTIGATION OF CORROSION RESISTANCE USING ELECTROCHEMICAL NOISE

Noise diagnostics present a simple, sensitive and almost non-destructive measuring method to evaluate corrosion resistance or corrosion sensitivity of metallic materials. Nowadays it is possible to transfer the operational possibility of electrochemical noise from laboratories to corrosion monitoring in practice. The most important advantages of noise diagnostics in comparison with conventional methods are:

- generation of information without external excitement of the system
- evaluation of corrosion tendency in material surface
- almost non-destructive measuring method
- fast testing of different system parameters
- often simplified test conditions to prove certain susceptibilities of the materials (lower cost, lower environmental pollution)
- cost saving due to shorter test time
- simple implementation of measurement and evaluation of test results

3 SCIENTIFIC AND TECHNICAL BASIS

The activation and passivation processes on the phase boundary between metal and electrolyte are considered to be the source of electrochemical noise. At the same time ongoing electrochemical reactions (as the basis for corrosion) are connected to local resistance and capacity changes. Therefore they cause charge changes at the phase boundary. At a later stage the electrochemical noise is also caused by changes in the substance transport process, changes in the local pH index, the temporary progress of local corrosion and the forming of small gas bubbles (hydrogen) on active surfaces.

Charge changes can be counted as potential or current peaks. This depends on the analysis method selected (galvano-static, potentio-static, current neutral to the outside). The concept is described as “noise" because the signals consist of a mixture of accidental and briefly identified items.

The first papers on the subject electrochemical noise were published by IVERSON in 1967. He showed by means of simple measurement arrangements that different materials show potential changes if corrosion occurs.

About 5 publications per year were noted over the following 15 years. Until 1983 the number of publications did not increase. Today about 30 publications appear every year. Further, manufacturers of electrochemical measuring devices have used electrochemical noise measurements in their development of hard and software over the last three years.

There are many reasons for the difficult start to the noise diagnostics concept. One is the unfortunate choice of the word noise. Although "noise" to describe the actual measurement signal is inaccurate and causes misunderstandings, the word noise has been authorized. Further, the word noise is usually considered in a negative sense. Recent years have shown that the noise signals produced also contain valuable information about the conditions of a system. Noise measurements are used in the monitoring of turbines and generators as well as in the determination of damage to engines.

Another reason for the difficult start to noise diagnostics was development of the field of measuring technology. When the first observations of noise processes occurred only the very clear and slow processes were observed. Besides, at that time only magnetic tapes and graph recorders were available for the recording of measuring data. Electronic measurement technology did not offer more accurate measurements either. Today it is possible to record electrochemical noise in scales of nA and µV due to the rapid development of computer technology and the most modern electronic modules.

A third reason are the changed points of view. Earlier the static systems were at the centre of attention. Today the measurement of electrochemical noise can also be carried out dynamically and noise diagnostics are more accepted than a few years ago.

The main reason for the increasing attention given to noise diagnostics is the promising possibility of recording the nucleus formation process by the measurement and evaluation of electrochemical noise. This method shows corrosion initiation a long time before the first damage becomes visible. It reduces the time required for measurement and offers the possibility of reducing accelerated corrosion tests in aggressive electrolytes. This technology also can be used to monitor the corrosion in technical facilities.

The "Institut für Werkstofftechnik und Werkstoffprüfung" of the Otto-von-Guericke-Universitat in Magdeburg and the "Institut für Massivbau und Baustofftechnologie" in Leipzig have developed a measurement stand for analysis using electrochemical noise. The "Institut fur Werkstofftechnik und Werkstoffprüfung" in Magdeburg has constructed some very modern systems which correspond to the most recent state-of-the-art technology. These systems already cover a large number of necessary analyses. Close co-operation with the manufacturers of all the components of the measurement stand guarantees, where necessary, an adjustment of the systems as required and also any new applications.

4 MEASURING OF ELECTROCHEMICAL NOISE IN REINFORCING STEELS

Apart from many other published investigations of local corrosion processes, some publications referring to the noise measurements of corrosion processes in reinforcing steels in concrete are also known.

DAWSON [1] reports on the corrosion monitoring of steel in concrete. Besides the usual mechanical, supersonic, chemical and physical tests, electrochemical testing methods were used e.g. for local measuring of the potential, recording of the polarisation course and resistance, impedance spectroscopy and last but not least measuring of the ECR. Comparing two signals a noise level up to 10 db higher was found if the concrete was contaminated with chlorides. DAWSON evaluates this observation as an indication of pitting corrosion. DAWSON concludes that electrochemical testing methods can present an alternative to conventional methods.

JOHN [2] reports on similar investigations. Extending DAWSON'S measurements, practical applications of the ECR for the control of the buttress walls of a swimming pool made of reinforced concrete were presented additionally. Measurements of the current noise between two electrodes of the same kind were reported in [3].

Investigations of the potential noise in reinforcing steels were carried out by HARDON [4], too. These investigations were performed with steels in chloride-contaminated concrete. He discovered a correlation between the standard deviation and the rate of corrosion.

MOOSAVI [5] reports on noise measurements of reinforcing steel under the effect of sulphate reducing bacteria. He observed clear potential fluctuations under these conditions. The results point out that the bacteria enter the concrete and then destroy the oxide film on the surface of the steel. A non-protective iron sulphide film forms at one point, that increases the risk of corrosive failure. Moosavi concludes that measuring the ECR is a suitable method for corrosion monitoring of reinforcing steel and with that the proof of microbiologically induced corrosion is possible.

Applications of the ECR to the investigation of stress corrosion in prestressing steels are unknown. However, there are many publications on the investigation of stress corrosion processes with other systems which report the successful use of the ECR [6-17].

5 TESTS PERFORMED AND THEIR RESULTS

5.1 Test Materials

The first tests were limited to two materials:

- Cold drawn strand St 1570/1770, d = 5,2 mm
  $f_{p0,2}$ = 1580 N/mm²
  f_p = 1815 N/mm²
- Quenched prestressing steel profile St 145/160, 9 x 5 mm²
  (Neptune steel of the old generation from Krupp)
  $f_{p0,2}$ = 1400 N/mm²
  f_p = 1510 N/mm²

In practice, cold drawn strand is regarded as insensitive and quenched prestressing steel is regarded as sensitive.

The following **figures 1a – c** show polished cross-sections of the surface area of quenched prestressing steel before the corrosion test and a photograph of the microstructure of the prestressing steel strand.

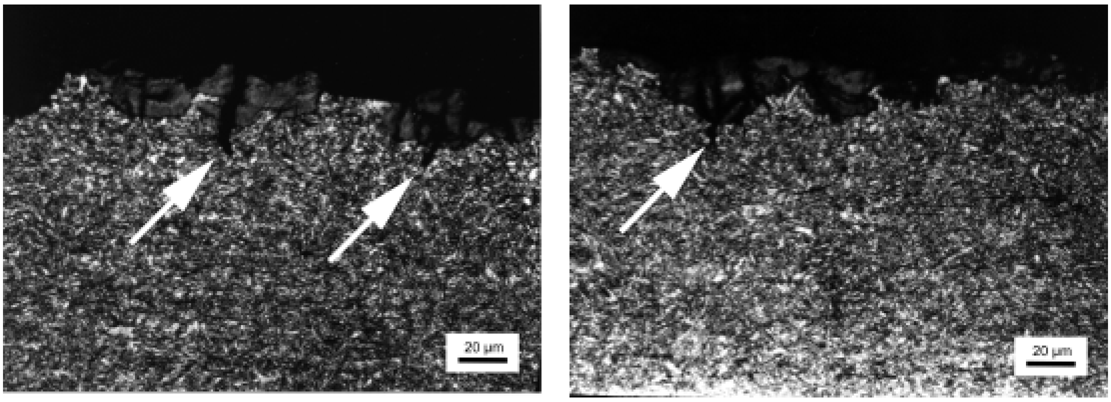

Figure 1a – b: Light-microscopy photograph of the boundary layer of St 145/160 (Neptune steel)

In figures 1a – b the layer of scale can be seen in two different places. This layer of scale is unevenly thick and porous, the pores reaching partly down into the primary metal. However, here it is very interesting to see that at the ends of the pores, cracks a few micrometers wide, reach into the primary metal. A probable explanation for this may be the application of this steel in a structural element.

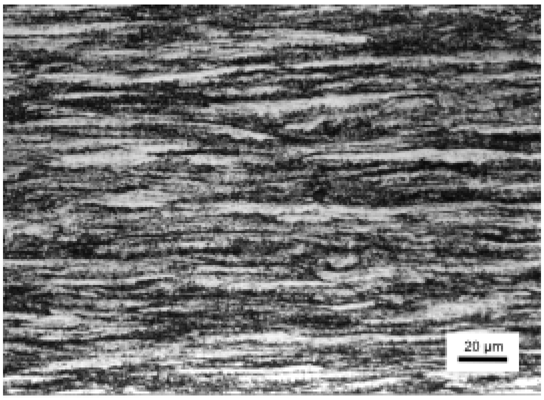

Figure 1c: Light-microscopy photograph of the microstructure of St1570/1770 (prestressing steel strand).

In figure 1c the banded microstructure of the prestressing steel strand is shown, which is caused by the manufacturing process. The surface, on the other hand, showed no layer of scale caused by the manufacturing process, but longitudinal grooves.

5.2 Test Performing

5.2.1 Program

The corrosion tests will be included in fundamental investigations in the laboratory (IWW Magdeburg) as well as tests under static and dynamic load (IMB Leipzig, IWW Magdeburg).

The following electrolytes will be used:

- 5 g/l Na_2SO_4, 0,5 g/l NaCl, 1 g/l NH_4SCN, pH = 7; (DIBt test)
- 5 g/l Na_2SO_4, 0,6 g/l NaCl, 1 g/l NH_4SCN in a saturated calcium hydroxide solution (pH > 12,3)

5.2.2 Investigations under mechanical load

With the laboratory testing stand at the IWW Magdeburg defined loads under electrolyte conditions can be realised. Here it is possible to apply static stresses, which are equivalent to those of prestressed prestressing steels.

The measuring equipment in IMB Leipzig was set up in accordance with the guidelines for ’’Licensing and monitoring tests on prestressing steels”. In addition a silver chloride electrode for electrochemical investigations was installed. With this relatively simple and robust test assembly additional measurements of the electrochemical potential and the recording of the potential noise in different ranges of frequencies could be performed. It must be mentioned that no voltage will be applied to the prestressing steel, so the system produces only own signals which are then measured. For this a multichannel potential noise measuring instrument manufactured by Jaissle GmbH, Waiblingen, was available. The digital measuring was performed using a TADA interface with a 14-bit-AD-transducer board and the software PCAA from IBP Hannover. The scanning frequency for the digital measuring was 100 values per second.

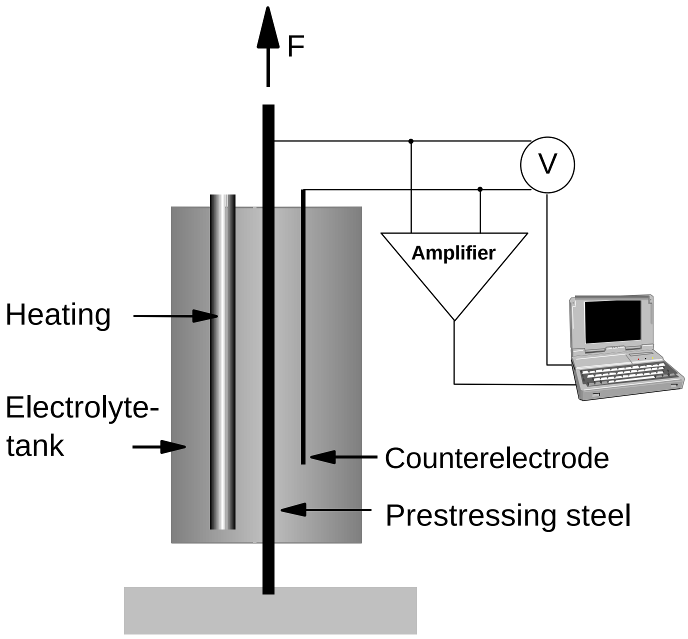

Figure 2: Measuring test stand in IMB Leipzig

Preparation for the measurements made it necessary first to determine the basic noise level of the total system. This was achieved by way of reference measurements in a “no load“ condition. Here a fundamental problem was immediately discovered. Caused by incipient crevice corrosion at the seal between the prestressing steel and the measuring gauge and possible corrosion phenomena at the water line, the first noise transients became visible, being clearly different from the basic noise (see **figure 3**).

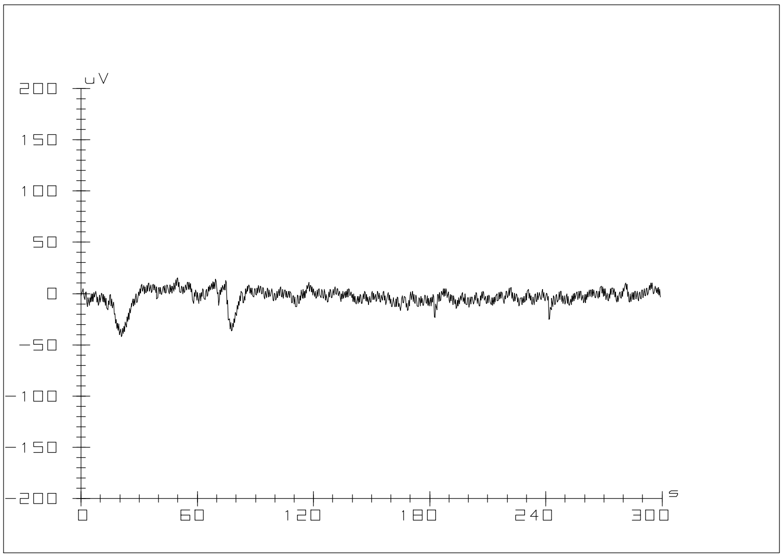

Figure 3: Reference measurement of the basic noise level with detection of noise transients by crevice corrosion, synthetic sheath water, St1570/1770 (prestressing steel strand), frequency range 0,01-1 Hz.

These phenomena could be avoided by careful covering of the transition areas between measuring gauge and prestressing steel and of the water line with silicone material. For each test, nevertheless, reference measurements were performed to be sure that the noise transients would not be caused by crevice corrosion phenomena.

5.2.3 First test results

The static tests were performed taking into consideration the parameters of the DIBt guideline. Only the testing time was clearly reduced. The result of a test with the quenched Neptune steel is shown in **figure 4**. The upper diagram describes the course of the measured potentials over the time. This conventional measuring gives no information on possible corrosion activities on the steel surface besides the decrease in the potential. As an example of the measuring of the ECR (here the potential noise) both lower diagrams show the results of the ECR measuring at different stages. While no corrosive activities were recorded between 24 and 30 h, distinct signals (transients) are recognisable between 96 and 102 hours. These are a clear indication of the onset of the corrosion process.

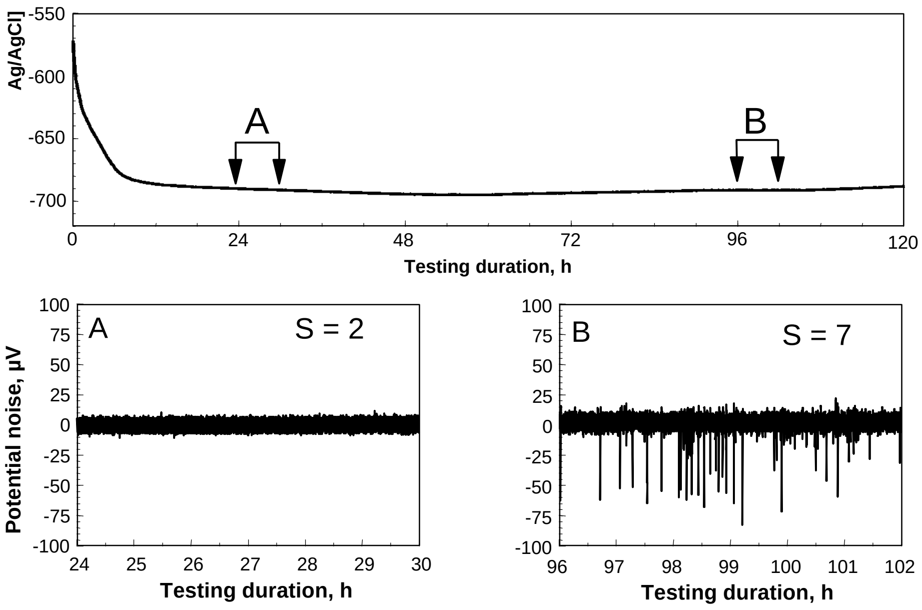

Figure 4: Test results on prestressed Neptune steel; preloading level 0,8 x R_m

The calculation of standard deviations over definite periods is a method for evaluating noise time graphs. Here a higher noise level, and especially transients, lead to a noticeable increase in the standard deviation. This also facilitates better perception and comparison of the tests one to the other. **Figure 5** shows an evaluation of the noise time graphs as shown in figure 4 by subsequent calculation of the standard deviation over periods of 5 min (corresponding to 30.000 measuring values each). A correlation to the noise time graphs is clearly visible and good differentiation of the tests is possible.

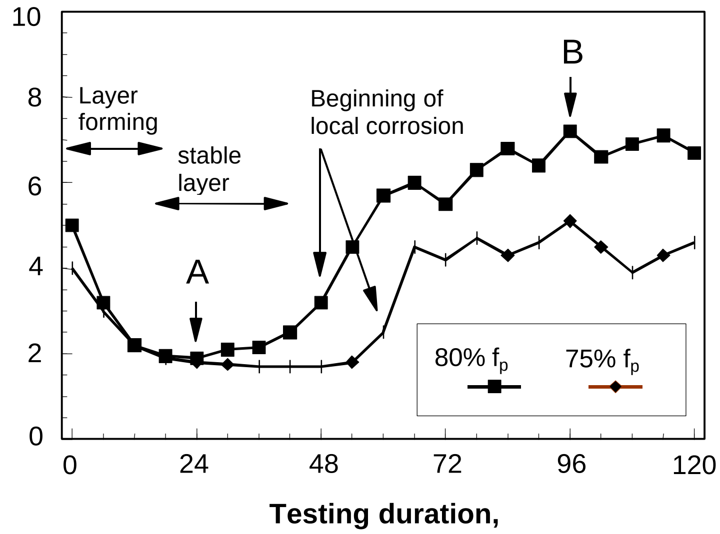

Figure 5: Evaluation of the test shown in figure 4 by calculation of the standard deviation, interval period 5 min

After about 48 hours and at a preloading level of 80 % of the tensile strength a sudden increase in the standard deviation can be observed, a clear indication of the onset of local corrosion. At a preloading level of 75 % the increase in the standard deviation occurs after about 60 hours. The resulting level is lower here.

Under the same conditions tests on cold drawn strand were also carried out (**figure 6**). However, indications of incipient corrosion could not be recorded.

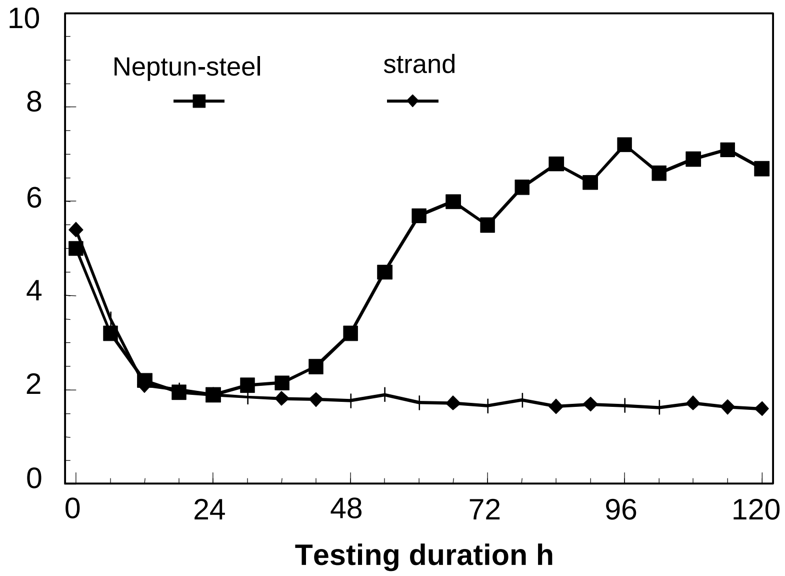

Figure 6: Standard deviation of potential noise during the test on cold drawn strand; interval period 5 min; preloading 0,8 x R_m

6 CONCLUSIONS

The first tests have shown that smallest modifications in the corrosion behaviour of prestressing steels can be clearly detected. Long term tests (> 120h) must still confirm which type of corrosion is related to the noise signals. By variation of the test parameters (increasing the temperature, larger concentrations of promoters or chloride etc.) specific test conditions can be developed which allow fast and reliable recording of the corrosion susceptibility.

How far the testing method can be used as an additional instrument for the developing of steels or for monitoring the manufacturing process must be shown by further investigations.

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