APPLICATION OF THE CORROSION TESTER IN CORROSION TESTS USING THE ACOUSTIC EMISSION METHOD

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ABSTRACT

The article presents an innovative method of corrosion tests using the acoustic emission method and the corrosion tester. The problem of corrosion occurring in ballast tanks and tanks carrying petroleum products is discussed. The acoustic method is presented which, due to the use of a unique corrosion tester, is used to monitor the course of corrosion processes in steel. The principle of operation of the corrosion tester, its construction and its use in Non Destructive Testing (NDT) are described in detail. Corrosion test results, obtained with the use of a corrosion tester, are presented. An analysis and a short discussion of the obtained results are given. The results of both the acoustic and metallographic tests prove the possibility of detecting material damage occurring during the operation of the corrosion tester, allowing determination of the course and type of corrosion damage.

Keywords: corrosion, hull steels, acoustic emission, corrosion tester.

INTRODUCTION

CORROSION

Corrosion is the phenomenon of spontaneous destruction of a material as a result of its interaction with the environment. This is caused by process, such as a chemical transformation of the material or deterioration of its physical properties. The surrounding environment is primarily the atmosphere and the solution with which the material is in contact. Until recently, corrosion was only associated with the oxidation of metals and their alloys, which were not resistant to oxidising agents. We are currently observing a growing interest in the corrosion of concrete polymers, semiconductors, vitreous materials, etc.

In addition to the usual corrosive environments (water, soil, humid atmosphere or industrial), microbiological systems, non-aqueous environments (petrochemistry), molten salts and metals (nuclear energy) are of increasing interest. It follows that corrosion means all phenomena related to the environment, both natural and artificial. Corrosion failure is one of the main causes of material loss. Economic losses due to metal corrosion are estimated at nearly 3-4% [1] of Gross National Income (depending on the country), with the largest proportion being iron alloys. It is estimated that 30% of the annually produced alloys of this metal are used only for the replacement of corroded elements. This should include costs related to downtime due to breakdowns or temporary protection measures. The task of corrosion engineering is to minimise and slow down this process.

Corrosion is most often classified [2-14] according to the material and environment in which it works, e.g. corrosion in a humid environment, corrosion in molten salts, gas corrosion, corrosion in non-aqueous liquids, corrosion in molten metals. Due to the type and structure of the materials, we can distinguish between: corrosion of active metals and their alloys, corrosion of passivating metals, corrosion of precious metals and their alloys, corrosion of organic polymers, corrosion of silicate materials, corrosion of modern materials and corrosion of concrete.

- There are three basic types of corrosion:
- Uniform corrosion,
- Pitting corrosion,
- Electrochemical corrosion.

The corrosion mechanism of various materials depends on the type of environment and the type of electrical conductivity at the metal-environment phase border. Corrosion is electrochemical for materials with high conductivity, while for those with low or no conductivity, corrosion occurs as a chemical or physicochemical process. Electrically conductive materials in various environments undergo electrochemical corrosion due to the formation of corrosive micro-cells. The mechanism of generating potentials in a wet environment is analogous to that in galvanic cells [9, 11].

ACOUSTIC EMISSION METHOD

One of the non-destructive testing methods [15-19] is acoustic emission, which determines the momentary generation of elastic waves caused by the process or the release of energy in a given material. Corrosion occurs in both cases. The acoustic emission method is a passive non-destructive testing method. The advantages of this method are:

- the possibility of inspecting individual elements of the structure,
- the possibility of examining and monitoring the entire large facility,
- the possibility of conducting real-time and continuous monitoring,
- the possibility of locating the sources of acoustic emission signals generated by damage or defects in the material, and
- the possibility of observing the processes at the place of their formation.

The processes accompanied by acoustic emission include changes at both the macro and micro level. Examples include:

- corrosion,
- plastic deformation,
- leaks in tanks or pipelines,
- delamination of coatings, and
- chemical reactions.

Acoustic emissions (AE) are sonic signals accompanying a change in the structure of the material during a sudden release of stored internal energy or by the process of formation of temporary elastic waves [5-13,15-18]. As the wave travels through the material, in the event of a defect, the wave is dispersed and reflected. This phenomenon is called an event and an acoustic wave is emitted, which is created as a result of the released internal energy. A wave formed in this way (Fig. 1(a) and Fig. 1(b)) is registered by the acoustic sensor. In the case of pitting corrosion monitoring, events arise from cracks in the passive layer that form on the surface of the corrosive metal. The events that become the source of wave emissions may be low-energy or high-energy events and determine the progress of pitting formation.
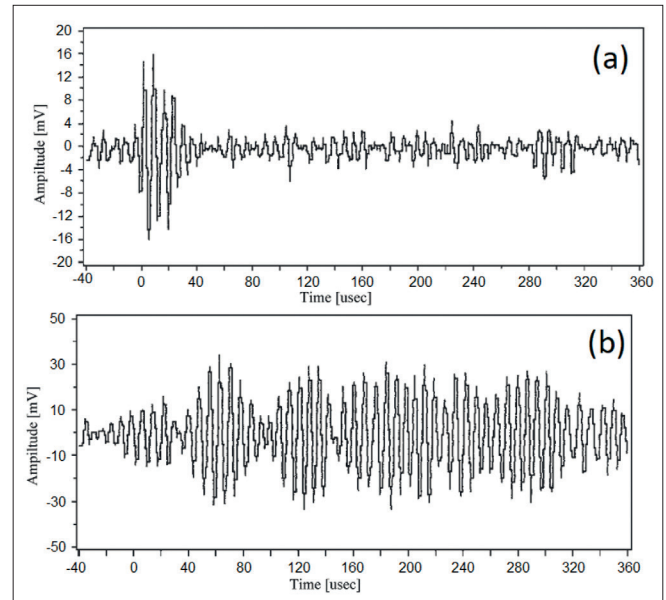

Fig. 1. Run of (a) short wave, (b) reflected wave [26].

The acoustic emission signal is characterised by such parameters as: energy, amplitude, number of crossings of the discrimination threshold, rise time and duration of the acoustic signal (Fig. 2).
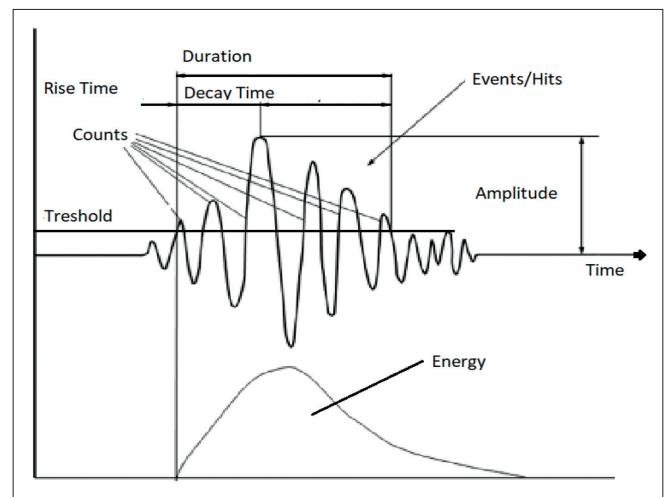

Fig. 2. A single acoustic emission signal [17].

The diagram of the acoustic emission test is shown in Fig. 3. Because of the AE system software, it is possible to visualise the registered measurement data in real time. When several sensors are used, with appropriate software algorithms, it is possible to locate the energy source of the acoustic emission

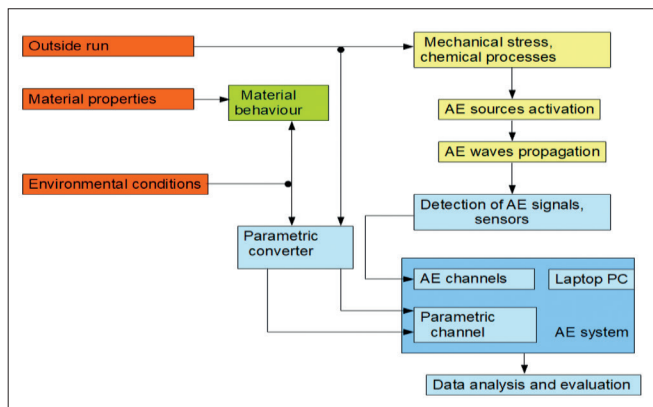on the basis of the difference in the time the wave reaches individual sensors.

Fig. 3. Diagram showing the acoustic emission system in operation.

Currently, this method is globally recognised [20-23] as being appropriate for the periodic testing of large devices, e.g. in the petrochemical or shipbuilding industry. The above-mentioned method complements other methods of non-destructive testing (NDT) very well. This allows for a more accurate assessment and verification of the detected damage.

MATERIALS AND METHODS

MATERIAL

Hull steel of category A was used in the tests, according to the classification in PRS(Polish Ship Registry) [24], from which the elements of both the measuring tank and the corrosion tester were made. Hull steels are normal (NSS) and high strength (HSS) steels, which are used in the production of structural elements used in the construction of hull elements of ships. There are several varieties. According to the classification of the Polish Register of Shipping (PRS), normal strength steels are divided into categories A, B, D, and E, while the abbreviations AH, BH, HE and HF 32, 36 and 40 describe constantly increasing strength, respectively (e.g. AH32). Hull steel of category A is one of the most commonly used steels in shipbuilding. Because of its excellent mechanical properties, chemical composition and welding properties, it can be used in the construction of ship sections, including the construction of tanks (e.g. ballast, cofferdam, etc.).

Normal strength hull steels (NSS) are characterised by a yield point of 235 MPa, while its maximum tensile limit varies from 400 to 520 MPa, depending on the category. An important criterion when selecting the operation of the hull steel, especially at low temperatures, is the fracture toughness test. For normal strength category A hull steel, the impact strength at room temperature (+20 degrees Celsius) should not be less than 27 J or 20 J (depending on the rolling direction of the test sample). For category B, the work of breaking a sample with a thickness of up to 50 mm should not be less than 27 J (20 J at a temperature of 0°C) and for steel D and E, it should be

the same, at temperatures of -20°C and -40°C, respectively. The mechanical properties may also be influenced by the additional thermo-mechanical treatment of the hull steel, the so-called 'delivery condition'. It is estimated that about 30% of all hull steels in the world are put into service after machining, most often in the controlled rolling (CR) condition and the thermo-plasticised (TMCP) condition.

The chemical composition of hull steels is very important for both their mechanical properties, such as tensile strength, and weldability. These factors may change, depending on the type and quantity of the alloying elements present in the composition of this steel. The main alloying elements are Manganese (Mn) and silicon (Si), the addition of which, not only increases the mechanical properties but also allows the removal of harmful elements, e.g. sulphur (Mn in an amount above 0.8%). The addition of 0.4% silicon assists deoxidation of the steel and also increases its plasticity and elasticity due to the strengthening of ferrite in the structure. Other alloying elements are: vanadium, aluminium, niobium, titanium, copper, molybdenum, chromium and nickel. The latter has a particularly significant impact on not only the mechanical properties, but also some physical properties. The addition of molybdenum, together with chromium and manganese, for example, increases the hardenability, yield point and tensile strength of the steel. Nickel, on the other hand, significantly improves the brittle transition temperature, shifting it towards lower values. The undesirable elements are mainly sulphur and phosphorus, the amount of which should not exceed 0.0035% in the alloy. Oxygen is also an undesirable element as it can have a negative effect on the plasticity or strength of the steel during the setting process. Therefore, the main deoxidisers are silicon and aluminium.

RESEARCH PROCESS

The research was divided into two stages. The purpose of the first was to collect the acoustic signal from the corrosion tester attached to one of the walls of the measuring tank made of hull steel of category A. The second stage consisted of carrying out metallographic inspections (macroscopic and microscopic examinations using an optical microscope, by KEYENS) of the corrosion damage on the surface of the tested corrosion tester, and estimating the size of this damage.

After assembling the measuring set and flooding the corrosion tester with a corrosive mixture (the chemical composition is given in Table 1), the purpose of which is to catalyse and initiate the corrosion processes taking place in the reaction tank of the corrosion tester, the corrosion tester was mounted on the inner wall of the measuring tank, as shown in Fig. 4. Then, with the use of magnetic grippers, VS-75(which frequency range from 30 to 120 kHz while peak is 75 kHz) type measuring sensors with EP 34 preamplifiers and VS-150 RIC(operating in frequency range from 100 to 450 kHz while peek is 150 kHz) sensors were attached to the walls of the measuring tank. The VS-75 and VS 150 RIC sensors were connected (using cables) to the AMSY-5 measuring system(produced by Vallen Systeme GmbH company) used for acoustic analysis. After

completion of the test, the corrosion tester was dismantled and thoroughly dried. Any loose corrosion products deposited during the test were removed from the surface of the stopper of the reaction cylinder. The prepared plug was then subjected to metallographic examination using a KEYENS microscope.

Tab. 1. The corrosion solution composition used during the tests.

Position	Mixture component	Mass concentration
1	H_2SO_4	10
2	HNO_3	10
3	NaCl	3

Fig. 4. Corrosion test tank with the KE-2 corrosion tester attached and the VS75-V and VS150 RIC acoustic sensors installed.

EQUIPMENT

For corrosion tests using the acoustic emission method, AMSY-5 measuring equipment from Vallen GmBH was used, together with a set of acoustic sensors (Fig. 5), the KE-2(given name for corrosion tester according to patent no. P.431331) corrosion tester (shown in Fig. 5), a corrosion test tank made of hull steel of category A, and corrosive solution (Table 1). All elements of the measurement set are summarised in Table 2.

CORROSION TESTER KE-2

This device allows simulation of the corrosion processes taking place at the test site. As a result, the acoustic emission monitoring system is able to separate the tester from the background noise, as well as locating the place of its attachment with a high probability. This type of corrosion tester should be constructed based on certain criteria:

- it must be made of a material that will be as close as possible to that from the test site,
- it must have a significantly active contact surface with the tested surface, so that the corrosion signal coming from the tester is captured by sensors located on this surface, which will significantly improve the location and allow for better 'audibility' of the signal against noise coming from outside the test area,
- the size of the tester must be sufficiently appropriate to be delivered and placed in the place of the test,
- the composition of the corrosive solution must be selected in such a way as to reflect the corrosion process in real conditions as faithfully as possible, but strong enough

Fig. 5. Acoustic sensors, type VS-75V i VS-150 RIC, used during the tests.

Tab. 2. List of elements used during the tests.

Position	Test Equipment	Number of pieces
1	Corrosion test tank	1
2	Corrosion tester	1
3	Measuring equipment (AMSY-5 from Vallen GMBH company)	1
4	Acoustic sensors: type VS-75-V with pre-amplifiers	4
5	Acoustic sensors: type VS 150 RIC	2
6	Magnetic grippers	6
7	Cables	6

to simulate the given conditions in the shortest possible time. In the case of laboratory tests, or if we are not limited in time, a solution can be exactly the same as the one in the environment whose destructive process on a given surface is to be observed. Otherwise, the process must be accelerated by adding appropriate catalysing factors,

- the tester must be built in such a way that it is tight and does not initiate corrosion at the test site and, when working, especially with an unstable corrosive solution, it is safe for both the user and the environment.

The above criteria are met by the KE-2 corrosion tester (Fig. 6.), which is used during corrosion measurements and accompanying acoustic events monitored by the VALEN system. It can be used to study both corrosion phenomena, occurring at a constant ambient temperature, and phenomena occurring at elevated temperatures, including in gases. It aims to collect the necessary data, which may help to build a better classifier in the future, and this will translate into better detectability of the corrosion process itself in real conditions.
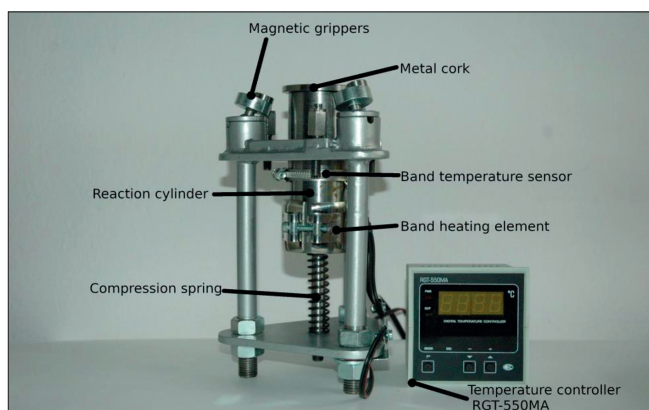

Fig. 6. The KE-2 corrosion tester with some of its elements.

The corrosion tester includes a reaction cylinder, among other things - constructed of ordinary hull steel of category A. The chemical composition of this steel is shown in Table 3. It is typical steel used in shipbuilding. The choice of this material is not accidental as it is this steel that is used to make tanks for the transport of crude oil and petroleum products, which are the subject of the research. The most realistic representation of the research conditions on tankers was the aim. Because of this solution, it was possible to simulate the corrosion process and record the acoustic signal coming from it without damaging the actual tank.

Tab. 3. Chemical composition of the material (Hull Steel of Category A according to PRS Classification) of the reaction cylinder *

Element	C_{max}	Mn_{max}	Si_{max}	Al_{min}
Share in [%]	0.23	2.50	0.50	0.04

* The table does not include the sulphur and phosphorus content, which are impurities, according to the requirements they should not exceed 0.035% of the composition.

RESULTS AND DISCUSSION

ACOUSTIC TESTS

Before the acoustic test itself, all components of the corrosion tester were well cleaned. After removing all impurities, the reaction cylinder and stopper were degreased with ethyl alcohol. Then, the corrosion processes in the tester were initiated, commencing with flooding the tester reaction tank with the corrosive solution (Table 1) to 1/3 of its volume. After placing and mounting the tester in the tank (Fig. 4) and connecting the VS150 RIC and VS75 sensors with preamplifiers, the AMSY-5 acoustic emission system was activated and the recording of the acoustic signal was started. The signal recording from the moment of flooding to its completion was about 30 minutes. The results of this measurement are presented in Fig. 7 and Fig. 8.

The presented test results prove the possibility of continuous detection of acoustic signals from the corrosion tester. It gives a stable and clear 50 dB signal that stands out clearly from the rest of the acoustic background during the measurement, which
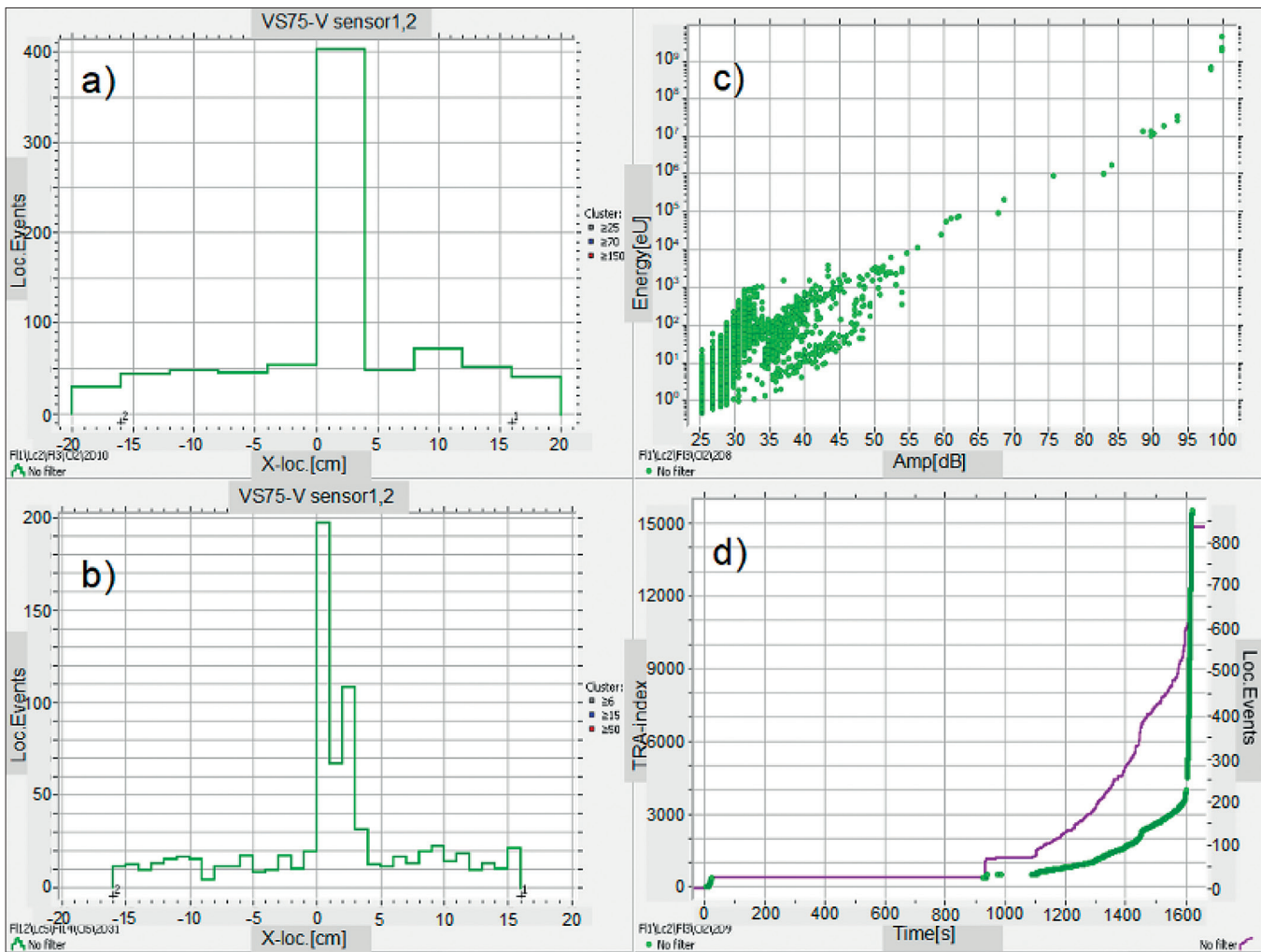

Fig. 7 The KE-2 corrosion tester and its background detectability for VS 75-V sensors, a), b) - the relationship between the location of the tester in relation to the sensors and the number of events recorded by the system, c) the dependence of the signal amplitude given in decibels (dB) to the released energy, d) graph of the measurement time and the number of events.
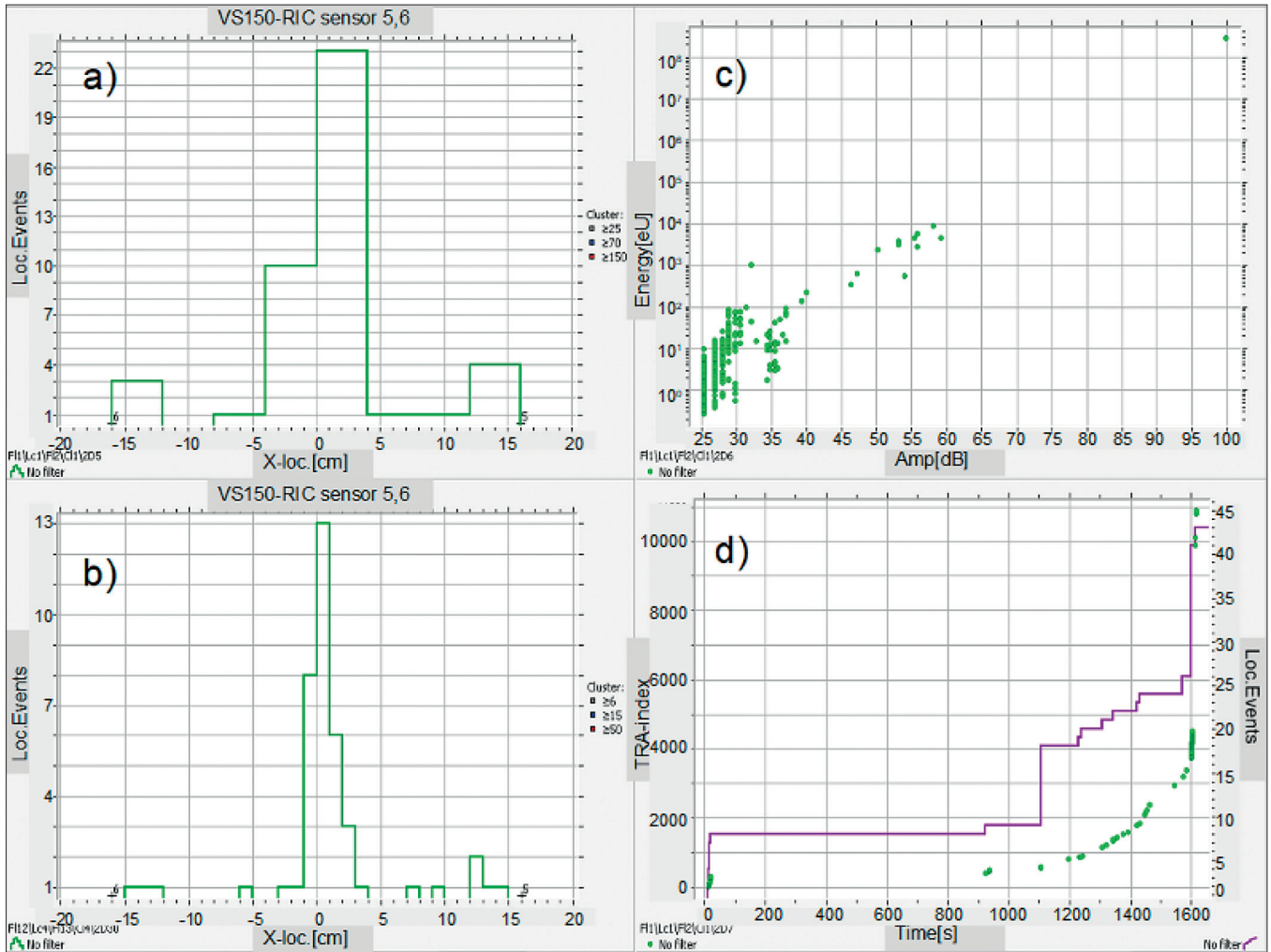
Fig. 8. The KE-2 corrosion tester and its detectability for VS150-RIC sensors. a), b). dependence between the location of the tester in relation to the sensors and the number of events recorded by the system, c) dependence of the signal amplitude in decibels (dB) to the released energy, d) dependence of the measurement time of the number of events

fluctuates around 20-30 dB, as shown in the graphs (Fig. 7c and 8c). This is a similar result to that found by [25], which is characteristic for the amplitude of the signal originating from corrosion occurring in steels in seawater. The corrosion signal obtained in the laboratory during corrosion tests also corresponds to the amplitude of the signal obtained during further tests carried out on real objects [26]. It can be observed that the tester is visible against the background noise coming from the laboratory. A clearly visible increase in energy in the places where the acoustic sensors of both VS75-V and VS150-RIC are attached, can also be observed. This proves not only the possibility of detecting the signal coming from the corrosion tester, but also the possibility of its partial localisation, which is very well illustrated in the graphs in Fig. 7a, 7b, 8a and 8b.

METALOGRAPHIC TESTS

Figures 9 and 10 present the results of metallographic testing of the plug covering the tester's reaction cylinder. The profile of the plug's surface shows extensive corrosion damage along the cross-section up to a certain point. Once that is exceeded,

the damage that occurs is very small. This is due to the way the corrosion tester is attached to the tank during the test. After careful examination of the photographs, a distinct line can be seen between the corrosive solution and the air trapped in the rest of the tester's reaction cylinder (Fig. 10).
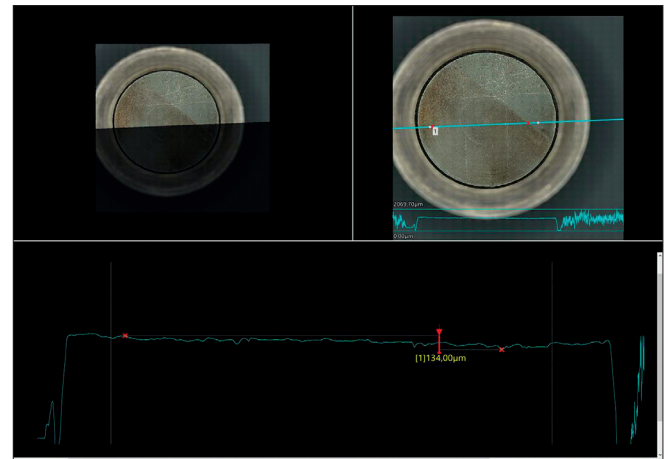

Fig. 9. The profile of the cylinder plug surface after the corrosion test.

It can be seen that, in part of the contact between the solution and the corrosive gas, the corrosion losses are interconnected pits, extending along the line of immersion of the cork of the reaction cylinder in the corrosive solution. Their depth, as shown in Fig. 10, is different. The greatest value of the depth, about 107-134 µm, is achieved in the chambers of the phase contact. The largest and most extensive complex of corrosion pits can be observed in Fig. 10. The photographs make up the cork profile and were built on the basis of the conceptual image stitching method implemented in the KEYENS optical microscope software. The magnification of a single photo was about 20 times (Fig. 9). Points 1 to 6 (Fig. 10) show a fragment of the plug surface corresponding to the measurement points of the profile cross-section and show the depths of the corrosion cavities collected in various places of the resulting corrosion pitting complex. The deepest pit in the complex has a depth of 110 µm, while the smallest has a depth of 0.32 µm. It should be mentioned that both pits presented in Fig. 9 and Fig. 10 were only selected as examples and do not show the full scope of the observed corrosion degradation of the material on the measured plug.
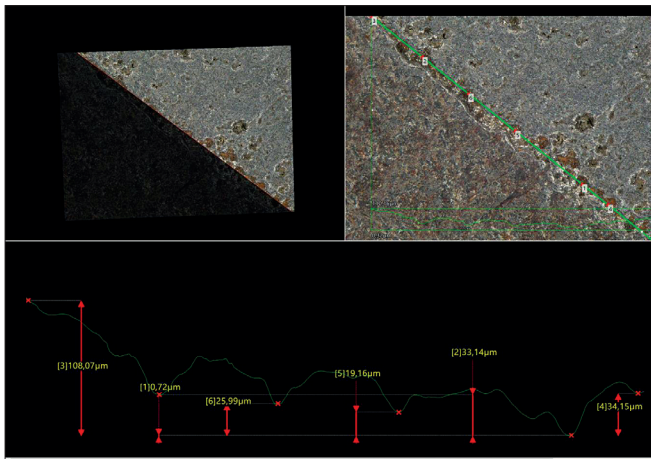

Fig. 10. The surface profile of the greatest corrosion damage observed on the surface of the plug from the reaction cylinder. As you can see in the photograph, the shape of this damage is extensive and consists of many pits connected with both. The deepest corrosion cavity is about 110 µm deep and the smallest is about 0.32 µm.

SUMMARY

The results clearly indicate that the corrosion processes taking place in the reaction cylinder of the corrosion tester are reflected in the course of the acoustic signal obtained during the test. It is also evident, from metallographic studies, that the corrosion process is most intense along the immersion line (the gas-solution phase contact). This may suggest that the main measure of corrosion is electrochemical and general. On the surface of the tested material, it should also be noticed that slight corrosion pits in the submerged part of the tester may suggest the initiation of pitting corrosion.

CONCLUSIONS

Analysing the results obtained during the laboratory testing of the tank using the acoustic emission method with the use of a corrosion tester, the following conclusions can be made.

- Corrosion Tester KE-2, as assumed, gives a stable acoustic signal under accelerated corrosion conditions and is locatable by the AMSY-5 acoustic system.
- The acoustic signal from the corrosion tester is clearly visible against the background noise in the environment, even in the absence of additional signal filtering. It should be noted, however, that this signal is catalysed by means of a corrosive solution and the actual character of corrosion in sea water or in a tank, therefore, may have a slightly different character.

The metallographic testing of the plug surface and the acoustic analysis of the corrosion process in the KE-2 corrosion tester clearly show that, apart from the standard uniform corrosion, we also deal with pitting corrosion at a later stage of progressive corrosion damage. Moreover. It could also be noted that the acoustic events shown by the acquisition system correspond to the formulation of the corrosion pits shown in the metallographic studies.

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