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APPLICATION OF ACOUSTIC EMISSION METHOD TO EVALUATE THE CHANGES IN THE PROPERTIES OF 17G1S STEEL AFTER LONG-TERM SERVICE

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ABSTRACT

17G1S steel is widely used in pipelines. Change in the physical properties of this material with time depends on the conditions of gas pipeline operation and pipe environment. Material damage due to operating time by far not always leads to a change of such standard characteristics of the material as σ_t, σ_y, K_{1C} and a number of others. At the same time, such material can be significantly damaged, but the traditional methods do not allow determining it. The objective of this work is to demonstrate the sensitivity of acoustic emission method to changes in 17G1S steel properties after 15 years of the main gas pipeline operation. Testing results show that the analyzed acoustic emission parameters change essentially under the impact of operating time, and they can be the characteristics for evaluation of the current state of the damaged material.

KEYWORDS: acoustic emission (AE), physical properties, AE monitoring, mechanical testing

INTRODUCTION

17G1S steel is widely used in pipelines, and, in particular, in gas pipelines. Change of some properties of this material with time is quite significant, and it depends on the gas pipeline service conditions and the pipe environment [1].

It is characteristic that material damage as a result of operating for a certain time does not at all always lead to a change of the material standard characteristics, such as σ_t, σ_y, K_{1C} and a number of others. As a result of that, such a material can be essentially damaged, but the traditional methods do not allow it to be determined.

In this work, the change of the steel properties was assessed by stretching the standard, undamaged samples and samples cut out of a pipe after long-term service, in a tensile testing machine with recording of the loads and elongation, as well as acoustic emission parameters (AE).

Unlike world practice [1–3], the technology of material state evaluation, developed at PWI of the NAS of Ukraine [4, 5], is based only on obtaining data on AE activity in the material and loading parameters, while the majority of the known studies require a multistep assessment procedure, in which AE method is assigned the role of the initial stage, at which AE activity in individual areas and coordinates of these areas are determined. Further on these investigations require additional studies of the material in the areas identified as hazardous by AE method. These investigations include cutting out reference-samples and studying their mechanical properties with further calculation of stress intensity factors, or, alternatively, application of additional NDT techniques, first of all ultrasonic testing (UT). These methods are used to determine the shape and dimensions of the defects, and then again calculations of mechanical properties are performed, taking into account the detected defect shape and with calculation of usually the same stress intensity factors, and the material state analysis is based on this characteristic. Such a multistep evaluation, first of all, is quite difficult to perform, and, secondly, it does not allow real-time evaluation of the material state.

EMA-type systems of several generations, developed at PWI, have a built-in technology of material state evaluation in real time with prediction of breaking load, which is based on image recognition [4–6]. It allows considerable acceleration of the qualitative and quantitative evaluation of the state without application of any additional methods with normalized accuracy (error within ±15 %) and probability of 95 %. This work presents, in particular, the results of prediction of the breaking load during static tensile testing of the samples.

We will obtain the results of stretching 17G1S samples in R20 machine. Figure 1 shows the loading scheme and position of the sample in the tensile testing machine.

The scheme given in Figure 1 is universal for the majority of AE tests of the samples, including temperature tests. Shown below are the diagrams of the readings of AE instrument during stretching of typical samples from as-delivered material and samples of damaged material, cut out of the pipe after 15 years of gas transportation. EMA-type AE systems can provide a rather large number of parameters in real time and during subsequent repetitions of the conducted measurements in the computer, in particular:

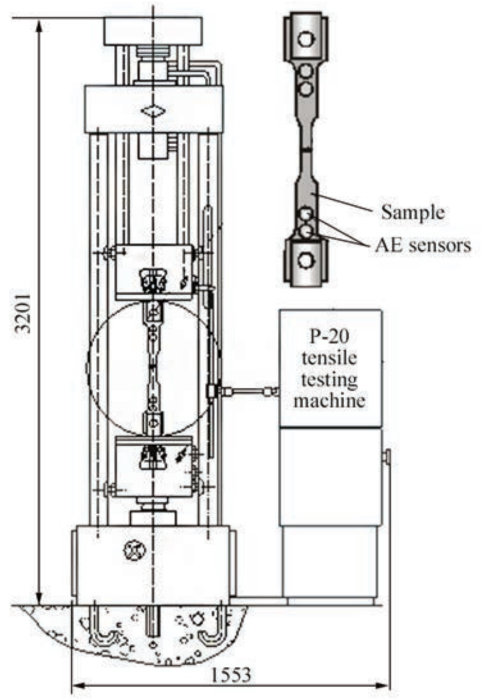

Figure 1. Sample and schematic of its mounting in R-20 machine

1. External force fields: in this experiment *P* is the current load, kg; *e* is the elongation, mm.

2. *A* — the maximal amplitude of the largest event being considered at this moment, mV, conditionally characterizes the volume created by the defect during its dynamic development.

3. *Rt* (*W*) — the time of increment of the greatest event in the sum of events at this time or its duration, μs, characterizes material hardening as a result of deformation.

4. *O* — the number of oscillations in an AE event, characterizes the amount of damage generated at this moment of time.

5. A_s — the summary amplitude of AE events during testing time, dB, characterizes the overall scope of the generated damage.

6. O_s is the summary amount of damage in the material during the analyzed time period, which is determined by the sum of AE event oscillations.

7. N_s — the AE events accumulated during the destruction process characterize the total amount of damage, developing during the considered time; and may not coincide with O_s.

8. A^2 is the energy consumed in defect formation, J.

9. A^2_s characterizes the summary AE energy consumed in sample destruction, J.

10. *n* is AE activity at a selected moment of time, 1/s.

11. *N* — the sum of events during the analyzed time, characterizes the number of defects developing over time, it can coincide with O_s.

12. *X*, *Y* are mediated with a given probability coordinates of the sum of events initiating at the moment of time being considered, in a certain area of the sample or structure, mm. The size of this area is determined automatically, depending on the tested object dimensions and AE sensor layout.

Considering that not necessarily all of the abovelisted parameters may be sufficiently indicative, such parameters as *P*, *e*, *A*, *Rt*, *n*, *N*, *X* will be considered in the window of the location array and plotted graphs. They provide a complete picture of the process of damage accumulation during testing, and visual demonstration of changes of the properties in the damaged material, compared to the metal in the initial state.

In addition to the abovesaid, EMA type systems have a functional which allows prediction of the breaking load in real time and after repeated viewing of the conducted measurements on the computer, the results of which are also given in this investigation.

Figure 2 shows the location screen of EMA program with instantaneous values of AE parameters, which appeared when testing a sample of as-delivered 17G1S steel. At this moment the window shows the following data:

1. Cluster coordinates are given at the top on the left, which indicate the predicted destruction site. These coordinates are determined more precisely as the sample is loaded.

2. Predicted breaking load (Destruction forecast) in the range of 9573–12087 kg is given at the top on the right, which corresponds to the actual data re-

corded by the instrumentation. It should be noted that the predicted value of breaking load appeared in the window at loading, which is equal to approximately 30 % of the actual breaking value which is equal to 11758 kg (Figure 3). Predicted values fall within the range of requirements to EMA type systems as to the destruction forecast of ±15 %.

3. Shown lower in the window is the bar of AE events combined into a cluster, which represent accumulation of damage in the sample with indication of *X* coordinate of the probable destruction site. A sample carrying AE sensors (their numbers and location coordinates) is schematically shown below.

4. Actual values of AE signals, accumulated in the tested area are shown still lower. Note than in Figure 2, which is a screenshot of EMA program at the moment of destruction forecast, AE events with large amplitudes are yet absent; they appear later during the sample destruction.

5. The diagram begins functioning with the testing start and follows the entire kinetics of destruction in its dynamics.

Detailed kinetics of sample destruction is presented in Figure 3. For ease of understanding the test data are divided into two graphs.

The graph in Figure 3, *a* shows:

1. Bars are the amplitudes *A* of AE events in the linear measurement modes. Shown on the axis on the left is the amplitude scale, where the maximum cannot exceed 500 mV.

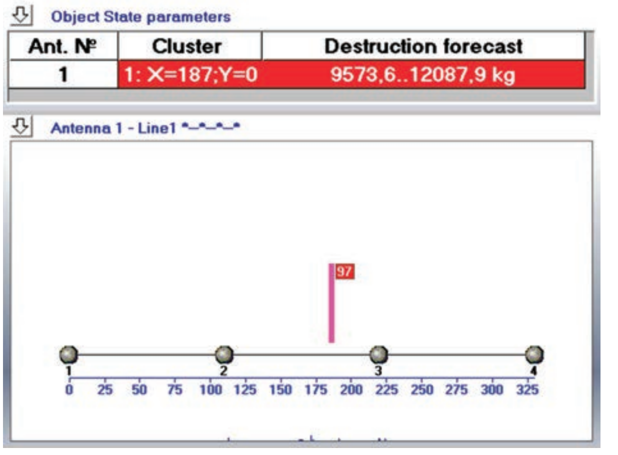

Figure 2. Location window of EMA program with AE data accumulated during testing of a sample in the initial condition

2. The line is the working load *P*. The value of actual breaking load of 11758 kg is shown on the axis on the right.

3. Points are the activity of *n* AE events in time. Value *n*, the maximum of which is equal to 18, is shown on the axis to the right.

The graph in Figure 3, *b* shows:

1. Bars show the time of increase of AE event amplitude up to maximum *Rt*. Shown on the axis on the left is *Rt* scale, where the maximum cannot exceed 65535.

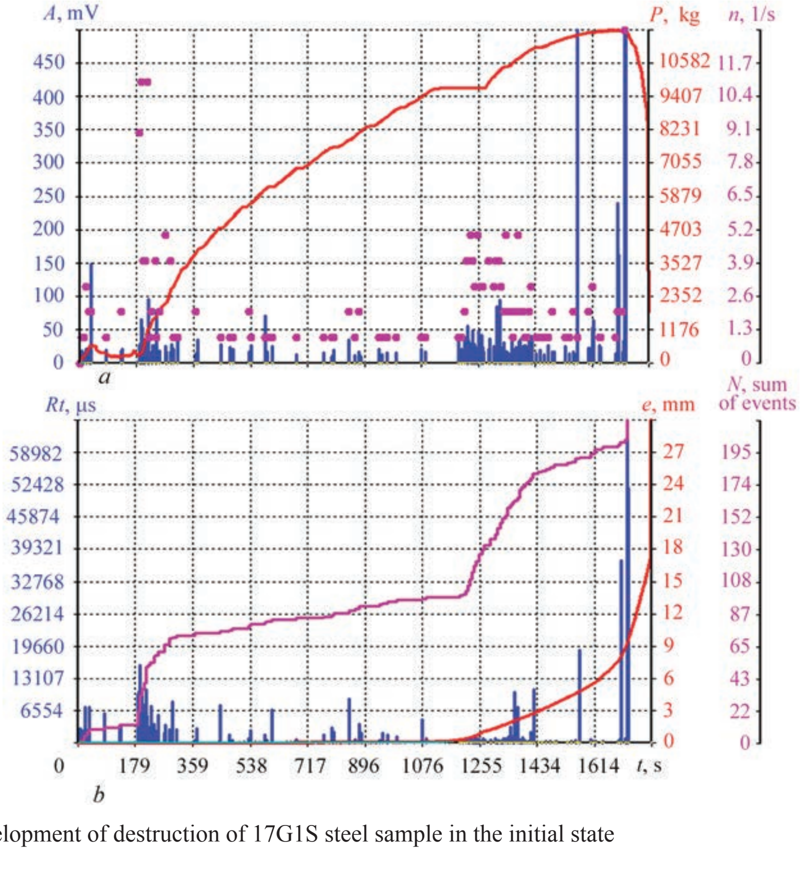

Figure 3. Graphs of development of destruction of 17G1S steel sample in the initial state

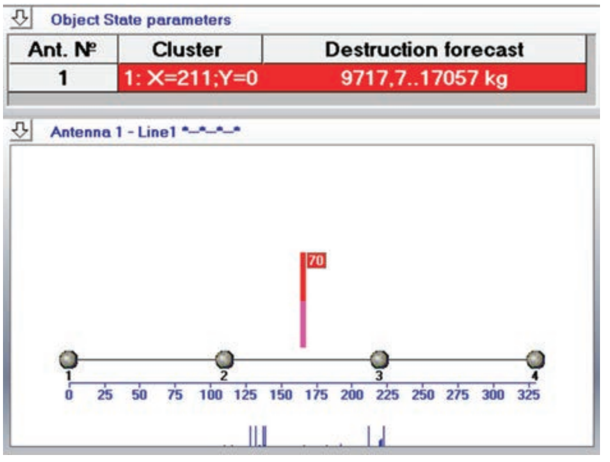

Figure 4. Location window of EMA program with AE data accumulated during testing of a damaged sample after 15 years of operation

2. Smooth exponential curve, which begins growing approximately after loading for 1000 s, shows elongation *e*. Marked on the axis on the right is value *e*, the maximum of which is equal to 30 mm – at the moment of sample destruction.

3. Steplike curve shows gradual damage accumulation in the sample, which is represented by event sum *N*. On the whole their quantity was equal to 217.

As we can see, the Keiser effect is absent in the initial material: AE events begin forming immediately after the start of loading, and their accumulation curve has a typical shape for undamaged material. Note the evident presence of a yield plateau, at which deformation is increased in the section of the horizontal loading curve.

Sample rupture is characterized by AE amplitude surges up to the maximum even before the ultimate strength has been reached and directly when reaching it.

The pattern is totally different for a sample cut out of a pipe after 15 years of operation (Figures 4, 5). Parameters given in Figures 2, 4 are the same, those on the graphs in Figures 3, 5 are also the same, but their nature has changed essentially.

The sample has hardened after 15 years of operation during gas transportation which is indicated by reduction of elongation from 30 to 15.9 mm at breaking load, which increased only slightly from 11758 to 11886 kg. Kaiser effect is clearly traceable: there are no AE events at the initial loading stage.

During operation the gas gradually penetrates into the pipe material, causing its gradual embrittlement, increase of the level of destruction rigidity, and aging of pipe material [4, 5]. This is confirmed by an abrupt reduction of the parameter of the duration of the event increasing part *Rt*, total sum of AE events *N* = 70 (there were 217 of them in the initial material), i.e. the amount of damage in the material after long-term operation decreases abruptly. Increase of

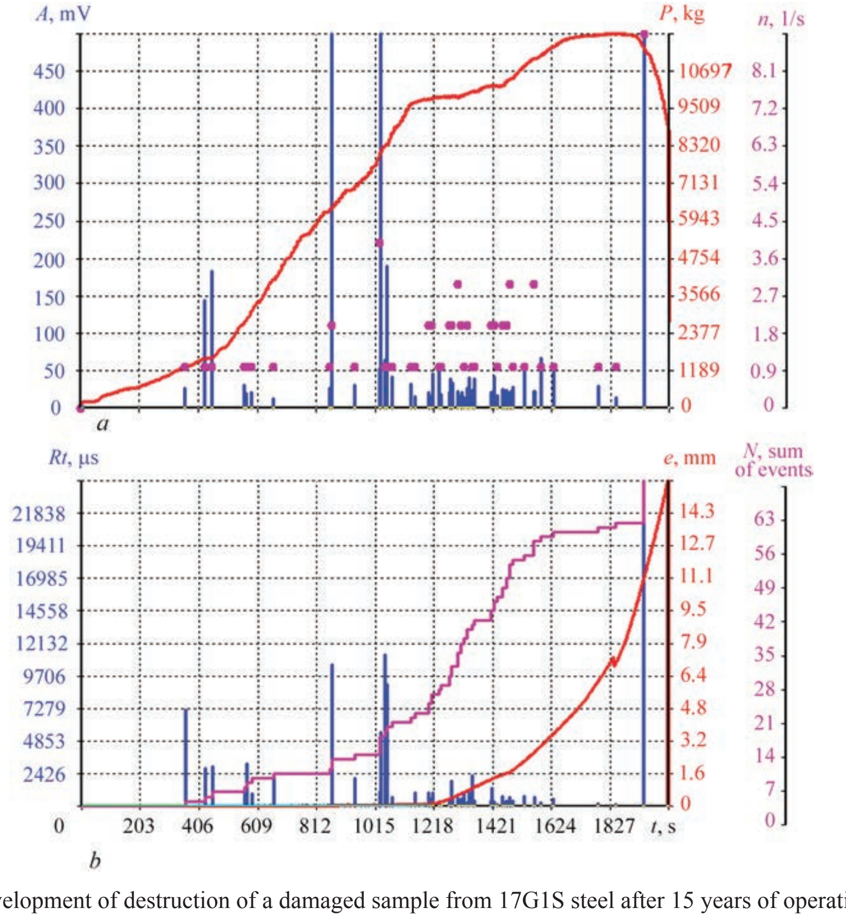

Figure 5. Graphs of development of destruction of a damaged sample from 17G1S steel after 15 years of operation

the percentage of AE events with maximal amplitudes relative to the number of the events proper is the result of embrittlement.

AE activity *n* became two times lower, which is also indicative of material hardening after operation.

Considering further the change of AE parameters during testing, one can see that in the damaged material AE events do not massively increase at once, but after a certain time. In this case it occurs approximately at $t = 400$ s and more intensively furtheron at $t = 1010$ s (active increase of sample deformation begins exactly from this moment), which, according to Kaiser effect, indicates that the pipe material was exposed to loading of approximately 27 atm in operation, and that the stress for the analyzed pipe (1020 mm diameter, 8 mm wall thickness) is equal to approximately 173.4 MPa). At the same time, it should be noted that the progressing embrittlement of pipe material can lead to destruction at emergency movements of the soil, through which the pipe is laid, as a result of washing out or shifting.

Thus, a sufficient sensitivity of AE method to changes in properties of 17G1S steel after long-term operation is shown, with preservation of the quality of state assessment and timely warning about the destruction and breaking load prediction.

CONCLUSIONS

1. AE method demonstrated sufficient sensitivity to changes of 17G1S steel properties after long-term operation. Practically all the analyzed AE parameters react qualitatively and quantitatively to the above-mentioned changes. It was possible to derive the respective qualitative and quantitative indices by comparing the results of static tensile testing of samples from the emergency stock with recording of AE parameters with the results of testing samples of a similar configuration, cut out in the main gas pipeline after 15 years of operation.

2. Continuous influence of the transported gas on the pipe material leads to an essential change of a range of material properties (see, in particular [4, 5]). Plasticity changes most strongly, which in the experiment is manifested by shorter time of AE event increase up to a maximum, reduction of the total number of AE events at considerable increase of the percentage of high-amplitude events. In practice ductility decrease leads to pipe material brittleness and to the risk of its destruction at emergency displacement of the pipe in the ground.

3. Conducted testing yielded data on the impact of previous 15 years of loading during the operation of 17G1S steel pipe on the change of this material properties which was manifested in a significant quantitative and qualitative change of a range of AE parameters.

REFERENCES

1. Junyu, Chen, Yunwen, Feng, Cheng, Lu, Chengwei, Fei (2021) Fusion fault diagnosis approach to rolling bearing with vibrational and acoustic emission signals. *CMES-Computer Modeling in Engineering & Sciences*, 129(**2**), 1013–1027. DOI: https://doi.org/10.32604/cmes.2021.016980
2. Amirabbas, Haidarpour, Kong, Fah Tee (2020) Finite element model updating for structural health monitoring. *Structural Durability & Health Monitoring*, 14(**1**), 1–17. DOI: https://doi.org/10.32604/sdhm.2020.08792
3. Nazarchuk, Z.T., Skalskyi, V.R. (2009) *Acoustic emission diagnostics of structural elements:* Sci.-Tekhn. Manual. In: 3 Vol., Kyiv, Naukova Dumka [in Ukrainian].
4. Nedoseka, A.Ya., Nedoseka, S.A. (2020) *Fundamentals of calculation and diagnostics of welded structures*: Manual. 5th Ed. Ed. by B.E. Paton. Kyiv, Indprom [in Russian].
5. Nedoseka, A.Ya., Nedoseka, S.A. (2020) *Fundamentals of calculation and diagnostics of welded structures:* Manual, Chapt. 7. 5th Ed. Ed. by B.E. Paton. Kyiv, Indprom [in Russian].
6. Nedoseka, S.A. (2007) Forecasting the fracture by the data of acoustic emission. *Tekh. Diagnost. i Nerazrush. Kontrol*, **2**, 3–9 [in Russian].

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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