The Acoustic Emission during Different Loading Rate of Specimens with Notch

Marek NOWAK *, Jerzy SCHMIDT *, Ireneusz BARAN *
* Cracow University of Technology Faculty of Mechanical Engineering, Cracow, Poland

Abstract. For the determining of rate loading on the recorded AE signals for S355 (18G2A) steel the static tensile test at ambient temperature were performed. For tests flat specimens with internal notch were prepared.

To characterize the recorded AE signals, the standard parameters describing the signal were selected, such as amplitude, number of hits, duration, rise time, counts. In addition, the frequency parameters of signal - Fcog (The frequency center of gravity) and FmaxAmpl (Frequency where the frequency spectrum has maximum amplitude) were used. Also for analysis two additional parameters characterizing the signal were created - RA and DA. RA was defined as the ratio of rise time and amplitude, DA as the ratio of the duration and amplitude.

Measurements were carried out by loading a material with five different speeds. The stage before continuous yielding of material was analyzed.

The some of tests presented in this article were realized under the project funded by Polish Ministry of Science and Higher Education.

Introduction

The acoustic emission (AE) is one of the non-destructive methods used in many fields of technology e.g. for testing of industrial structures, components, etc. The industrial tests are carried out on different objects, sometimes they are small, but sometimes the objects are with very large volume and then the loading process is very long. From the other hands sometimes the loading is realized by staff from other company and the loading is performed with higher rate that assumed (access in standard).

For testing of pressure equipment during the pressure test the maximum loading speed is defined in the standards. For the hydraulic test the maximum rate of loading is defined as 5% of maximum load and for pneumatic test this value is 1%. However, the minimum rate of loading is not determined.

Regardless of the duration of the test, the quantitative and qualitative criteria of AE signals for the evaluation of AE sources are the same. Therefore, it is important to verify that the AE signal parameters significantly depend from rate of loading. This will give you the answer, if a fact that process is very slow should be taken into account for evaluation of AE sources and evaluation criteria should be amended.

The material, equipment and methodology of tests

For tests the S355 (18G2A) steel were selected, which is used for build of industrial objects (e.g. flat bottom storage tanks, pressure equipment, bridges, other constructions) often tested by AE method.The chemical composition and theoretical mechanical properties S355 steel are presented in table 1.

Table 1. Chemical composition and mechanical properties of S355 steel

Chemical properties [%]									
C	Si	Mn	Cr	Mo	Ni	V	W	S	P
0,2	0,2 ÷ 0,5	1,5	Max 0,03	-	Max 0,03	-	-	Max 0,04	Max 0,04
Mechanical properties			Tensile strength [MPa]		490 ÷ 630		Yield point [MPa]		335

For the determining of rate stress on the recorded AE signals for S355 (18G2A) steel the static tensile test at ambient temperature were performed. For tests the mechanical testing machine Zwick with hydraulic grips was used.

The flat specimens with cross section 24mm x 4mm were prepared and three AE sensors were mounted along the length of samples. The tests were carried out on samples without and with notch as are presented in figure 1. The measurements for influence of loading rate on AE parameters were performed on samples with notch length 2,4 mm.
The Vallen AE system and 150kHz rezonant sensors with external preamp 34 dB were used.

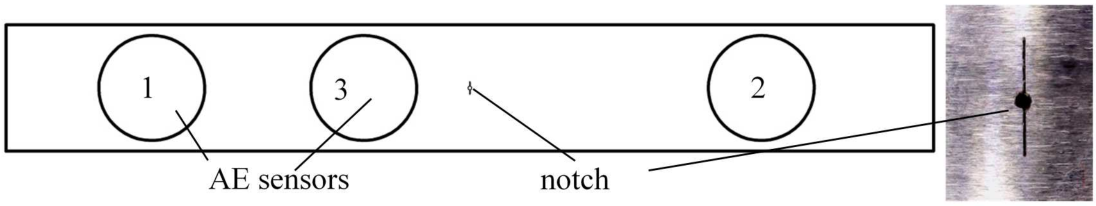

Fig. 1. The scheme of samples with notch and layout of AE sensors

Preliminary tests

At the beginning were performed the static tensile tests on samples without notch for study of real mechanical properties of tested material. The real tensile strength was used for determining of loading rates in next tests. The tensile strength was 520÷528MPa and yield stress 380÷385MPa. The metallographic examinations were also performed.

During the examination of pressure equipment according with EN 14584:2005 standard, the maximum pressurisation rate is defined as 5% of pressure test per minute for hydraulic test and 1% for pneumatic test. For tested material the 5% of maximum load was 26MPa/min, i.e. 0,43MPa/s and it was the base value.

The first measurements were also useful for determining the acquisition of AE parameters. In figure 2 there are presented the results for sample without notch – the amplitude and intensity during loading. The red color graph is a stress-strain curve.

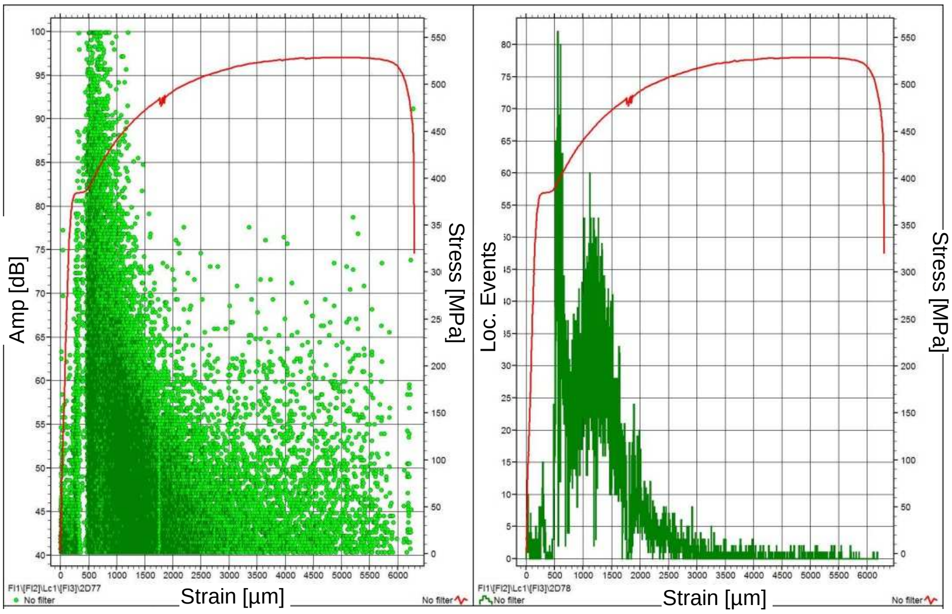

Fig. 2. Amplitude and intensity of AE signals for sample without notch

The assumed rate value (0,43MPa/s) corresponded to maximum rate for hydraulic test of pressure equipment. For determining of influence loading rate on AE parameters, the following rates are selected - table 2.

Table 2. The loading rates for static tensile tests

Stress rate defined in the user program of a testing machine [MPa/s]	Stress rate σ/Time [MPa/min]	Stress rate as a percent of maximum load [% σ_{max}/min]
0,0215	1,29	0,25
0,086	5,16	1
0,43	25,8	5
0,86	51,6	10
2,15	129	25
10,75	645	125

Signal analysis

During the measurements with different stress rates, within certain ranges increasing of load, the continuous AE was observed. At that time it is impossible to record the all AE parameters. Also the industrial tests are generally realized with the load that would not result the plastic deformation, therefore the time before was analyzed.

For the analysis was used the three AE sensors and linear location algorithm. The sensors close to grips were used as a combined channels. It means that this is used as a guard channel, when it is the first-hit channel and as a normal channel else.

In Figure 3 and 4 show the results of applying of location algorithm as a graph of number of located events and amplitudes along the length of the sample and the amplitudes of signals as a function of displacement for the selected values of rates stress.

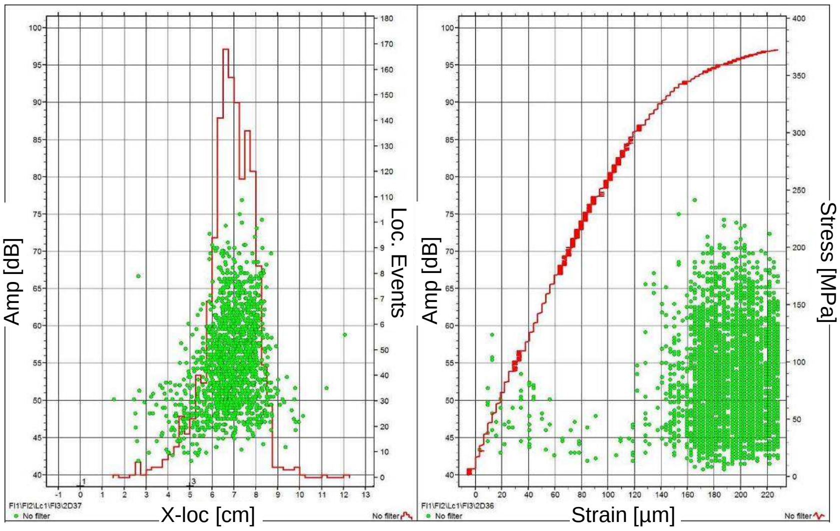

Fig. 3. Amplitude of located signals for loading rate 0,0215MPa/s

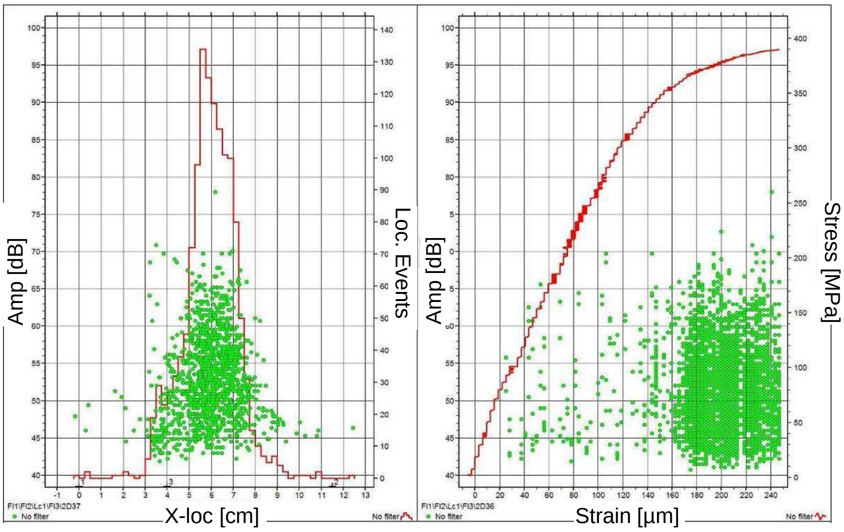

Fig. 4. Amplitude of located signals for loading rate 2,15MPa/s

Compared the maximum amplitude of located signals and value of amplitude of main band. The results are presented in figure 5.

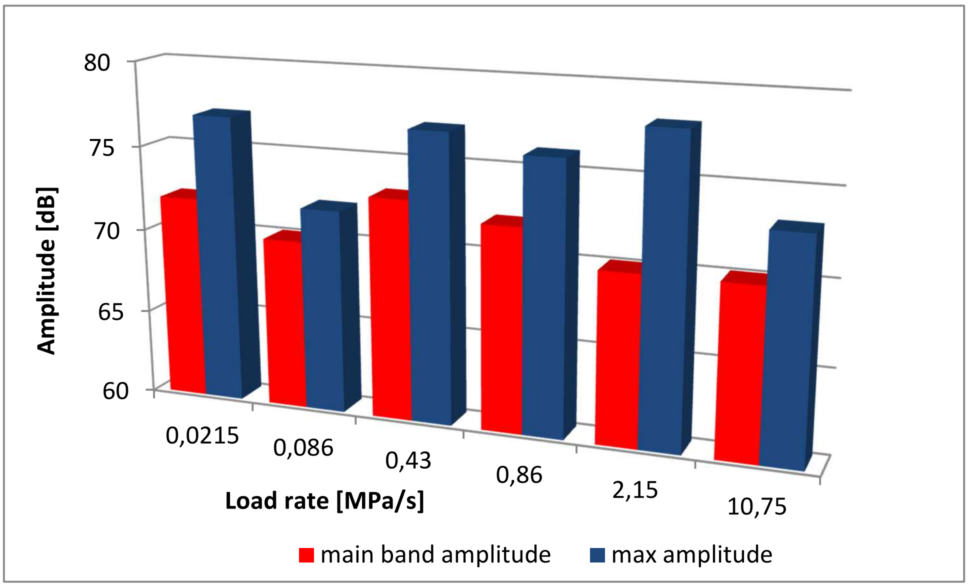

Fig. 5. The values for maximum amplitude and amplitude of main band of signals for different loading rates

The differences of amplitude band value are small and not found the correlation between their values and stress rate.

One of the basic factor which describes the AE source in the case of using the location algorithm is the number of located events. For the samples with notch 2,4mm length the maximum intensity is at the inflection point of the stress curve. The one of the example is presented in figure 6, and in figure 7 the maximum intensity of located events for every stress rates are presented. The graphs are for located events per strain (5µm) and located events per time (1 second).

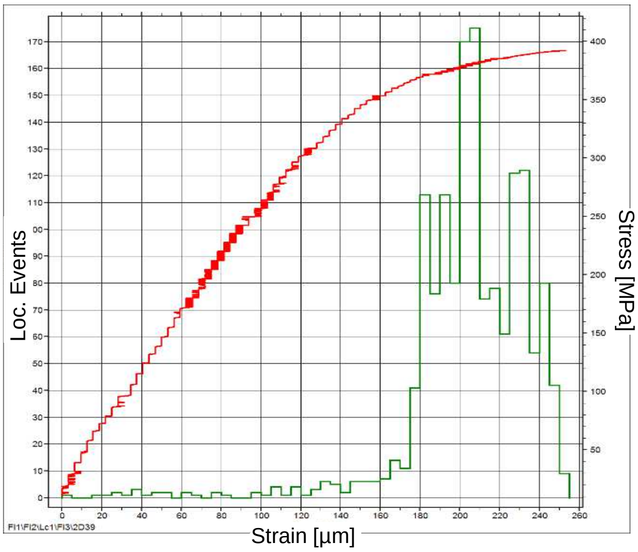

Fig. 6. Intensity of AE signals for loading rate 0,43MPa/s

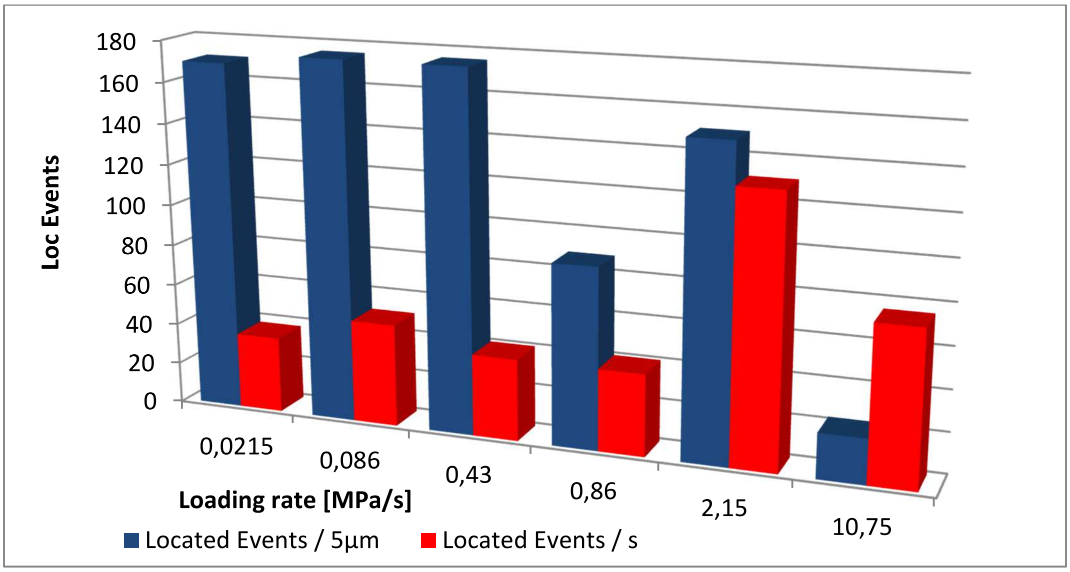

Fig. 7. The intensity of located events for different loading rates

For the loading rates up to 0,43MPa/s the numbers of located events per second are similar. For high value of velocity, the numbers of events are much higher. This is due a very fast plastic deformation of material which generates a lot of AE signals in a very short time. In relation to the displacement, the number of located signals is the largest for low-speed loading.

Important parameter characterizing the AE signal and used in the evaluation of a source located on industrial objects is the energy of the signal. The energy values for each loading rates are shown in figure 8.

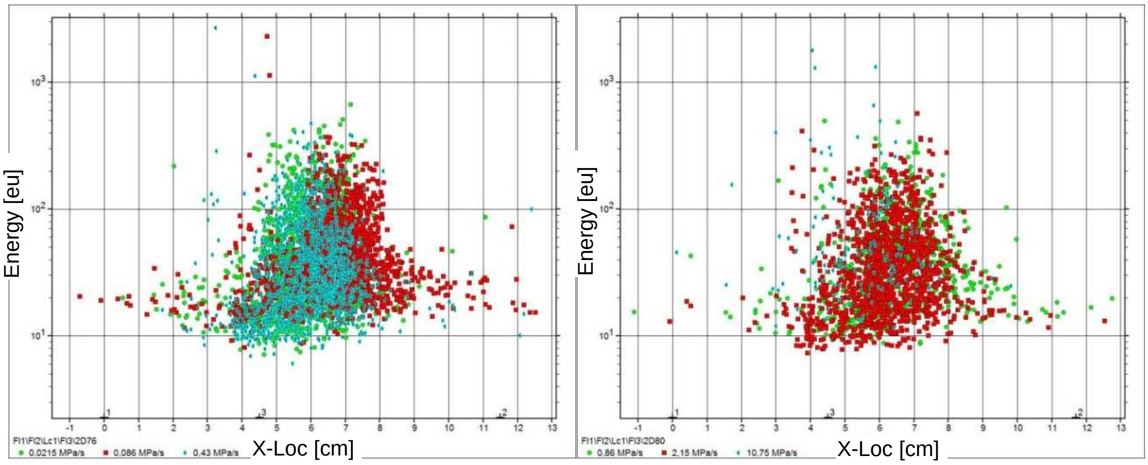

Fig. 8. Energy of located events for different loading rates

The signals energy were on similar level and did not depend on loading rates. The following parameter which was analyzed was a rise time. The main band of signals rise time for extreme loading speed values i.e. 0,0215 MPa/s and 10,75MPa/s was up to 120μs and was lower compared to the signals recorded at other loading rates. For these speeds the rise time is within 140 ÷ 180μs.

The next analyzed parameters were duration and the number of counts. Significantly they changed only for the loading rates of 10,75MPa/s.

The used software allow to determine the values characterizing frequency of signals such as a frequency center of gravity (FCoG) and the frequency where the frequency spectrum has maximum amplitude (FmaxAmp). Figures 9 and 10 show the number of events of a given frequency value FmaxApl and FCoG. Main frequency bands of signals overlap and the differences are small - in the range till 5 kHz.

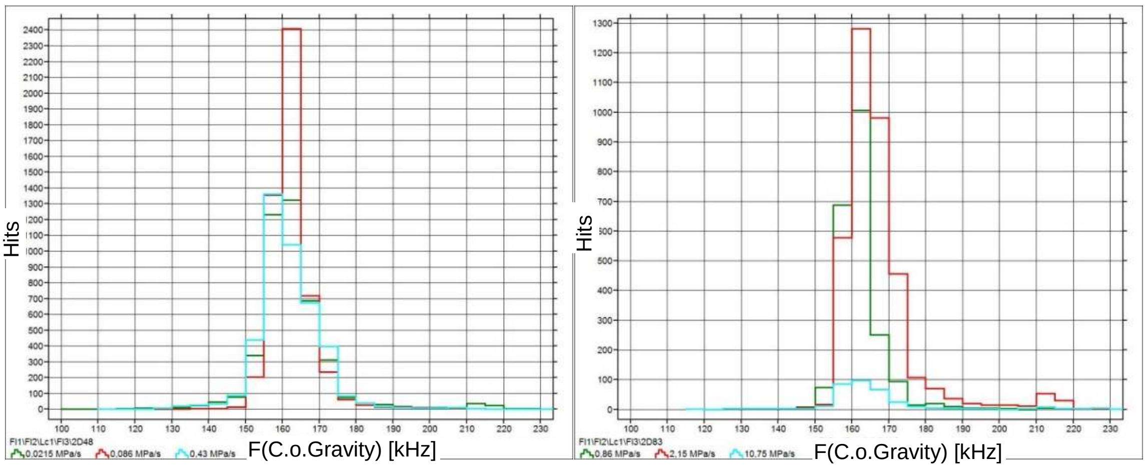

Fig. 9. Number of events for a given frequency center of gravity

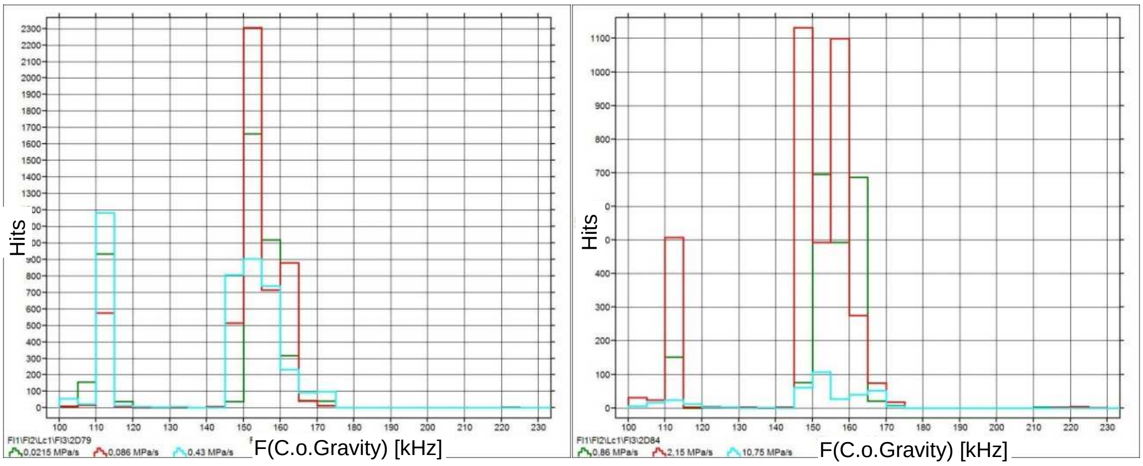

Fig. 10. Number of events for a given frequency where the frequency spectrum has a maximum amplitude

For the purposes of analysis and verification of changes of signal parameters, or their dependencies, additional parameters were created RA and DA. RA parameter is defined as the ratio of rise time and amplitude (Rise time / Amplitude) and expressed in ms/V. This parameter is used, for example for classification of the material cracks in the structure.

The second parameter – DA, created for the show changes in the parameters of recorded signals was defined as the ratio of the signal duration and amplitude (Duration / Amplitude) and is also expressed in ms/V.

The average value of the RA parameter during the most intense of AE signals for the loading rate of 0,86MPa/s and smaller it is at a similar level (40 to 50 ms/V) – figure 11, while for high-speed loading, i.e. 2,15MPa/s and 10,75MPa/s the average values of this parameter are 100 and 300ms/V.

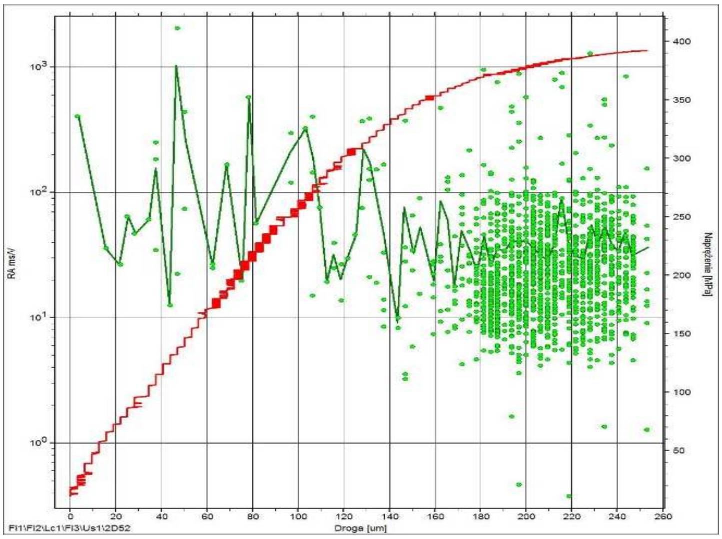

Fig. 11. The RA parameter and average value of RA for loading rate 0,43MPa/s

The changing of rate stress also affects on the average value of the parameter DA, since for higher values of rate, this parameter increasing from 500 ÷ 700ms/V for a rate equal and less than 0,86MPa/s up to 800÷900ms/V and 1500÷2000ms/V for rates of 2,15MPa/s and 10,75MPa/s. These relationships are shown in Figure 12.

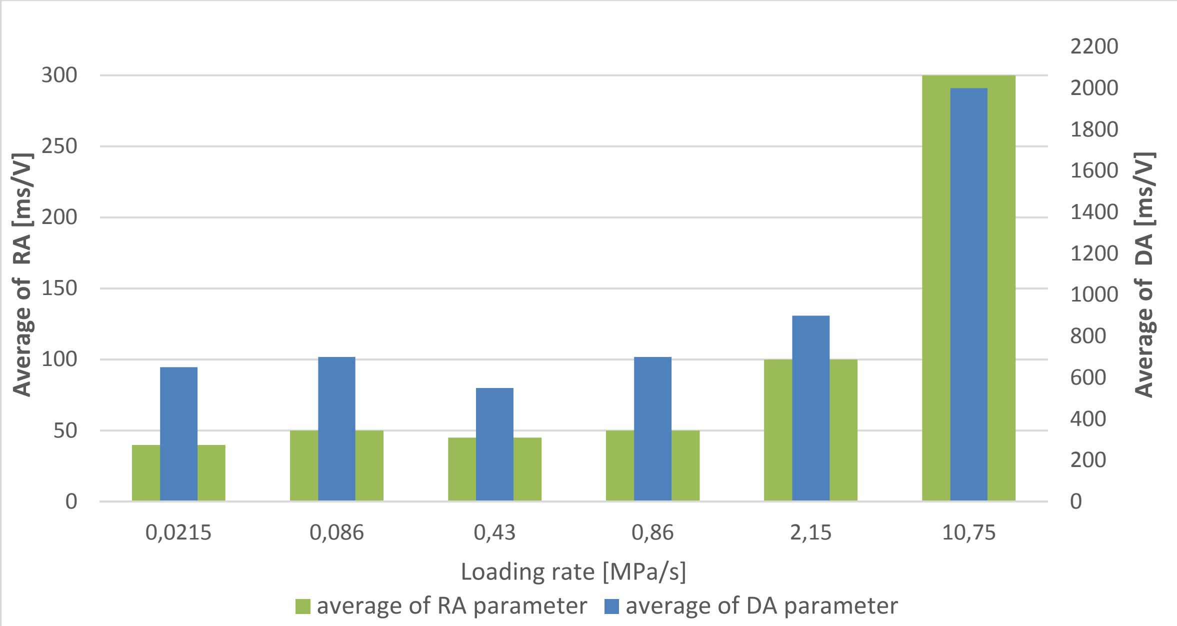

Fig. 12. The average values of the RA and DA parameters for different loading rates

Conclusions

The assumed methodology allowed to determine the influence of loading rates of structural steel with damage on AE signals.

For comparison of AE parameters at different rates, the time before continuous yielding of the material was analyzed.

The analyzed standard parameters of AE signals, for rates stress used in industrial research does not depend on the rate.

For high-speed loading, the created additional parameters RA and DA describing the AE signals change their values significantly.

While maintaining defined in the standard the maximum loading rate of industrial equipment made of steel S355, it is not necessary to subordinate the AE criteria loading rates.

References

[1] Christian U. Grosse, Masayasu Ohtsu: Acoustic Emission Testing, Springer, 2008

[2] Zhiyuan Han, Hongyun Luo, Hongwei Wang: Effects of strain rate and notch on acoustic emission during the tensile deformation of a discontinuous yielding material, Materials Science and Engineering A, 2011

[3] EN 14584:2005 Non-destructive testing — Acoustic emission testing — Examination of metallic pressure equipment during proof testing — Planar location of AE sources

[4] EN 1330-9:2009 Non-destructive testing. Terminology. Terms used in acoustic emission testing

[5] Vallen Systeme GmbH, AMSY-6 Handbook