APPLICATION OF ACOUSTIC EMISSIONS IN TESTING OF MATERIALS AND STRUCTURES

Zijah Burzić[1], Srđa Perković[1]
[1]Military Technical Institute, Ratka Resanovića 1, Belgrade, Serbia, zijah.burzic@vti.vs.rs

Keywords: Acoustic emission, Deformation process, Sensor, Testing of materials

ABSTRACT:

Deformation in material prone to acoustic emission is caused by plastic strain or crack initiation and growth. Acoustic emission belongs to the active group of testing methods whereas the acoustic emitting signal is generated during processes of deformation, defect initiation and propagation. Application of acoustic emission in testing materials and structures enables early detection of defects that develop in service that may cause considerable decrease in reliability and operational safety, including loss in structural integrity. Typical examples of applied acoustic emission in monitoring the pressure vessel state and in testing precracked composite specimens are given.

1. INTRODUCTION

Acoustic emission is relatively new technique of non-destructive testing (NDT). It is an active method, since by its application it is possible to detect when deformation takes place and defect or crack occur, and in most cases also where it happened, compared to other NDT methods which have no capacity for such detection.

In the range of elastic behaviour of material acoustic emission is negligible. With the occurrence of plastic deformation acoustic emission significantly increases, enabling to determine the limit between elastic and plastic behaviour. Acoustic emission intensity increases more with plastic deformation development.

Acoustic emission is very high when crack initiates and fracture develops and is a special convenience in tests for fracture mechanics parameter determination and monitoring of structural integrity in service. These properties make acoustic emission prospec-tive for use since, with modern design of components and structures based on mechanical properties of structural materials, it contributes to reliable structural life assessment [2].

In materials with pronounced acoustic emission defor-mation processes mostly occur from:

- action of forces beyond yield strength that causes plastic deformation or crack occurrence and growth, depending on material type and local stresses within;
- variable forces applied to the material, e.g. material fatigue;
- stress corrosion;
- development of crack at low temperatures.

Acoustic emission may be applied for detecting these processes. The characteristic acoustic emission signal can always be produced and may be connected to the material state and behaviour. It is to notice that experience and skill are necessary for testing preparation and performance, but also in the analysis of obtained results.

2. ACOUSTIC EMISSION OCCURRENCE AND RECORD

An acoustic emission signal can be continuous or discrete. The signal of continuous acoustic emission is of similar form as noise. The only difference is that its amplitude is variable according to the acoustic emission activity. This acoustic emission type in metals is connected with disloca-tion movement at plastic deformation, [2].

Discrete acoustic emission occurs from the partial release of strain energy in discrete sufficiently remote instances in time that do not allow overlapping of wave blocks formed in this situation. The duration of these blocks is usually short and takes tens of microseconds down to several milliseconds. Sources of discrete acoustic emission as twinning, initiation and propagation of micro- and macro cracks are cited elsewhere in literature. Signal amplitudes of acoustic emission are normally higher than amplitudes of continuous type of acoustic emission signals, [1, 3].

3. ACOUSTIC EMISSION SIGNAL PROCESSING

Proper processing of the obtained signal will establish the relation between changes in the material developing under external loads and the acoustic emitting signal. The processing mode depends on two basic factors:

- test type (laboratory research, quality control of structure, monitoring of material behaviour);
- the purpose of processed acoustic emission signal results.

Several methods of AE signal processing are developed:

- events count;
- counting of oscillations recorded by sensor;
- energy measurement;
- amplitude analysis, and
- spectral analysis.

The most frequently used method in our test included counting oscillations recorded by sensor. The principle of the method is in counting each pass above the decision threshold level of the signal on sensor output [4], whereas the number of these passes in a single event increases with event amplitude. An illustration of this procedure is given in Fig. 1. The total number of oscillations recorded by sensor for a given decision threshold depends on the frequency of the event, on one hand, and on amplitudes of these events, on the other.

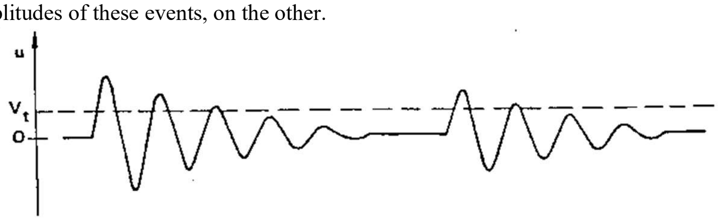

Figure 1. Scheme of oscillation count recorded by sensor with amplitude passes over given level marked by dashed line, [4].

When a defect in a loaded material emits an AE signal, its location can be determined by applying three or more sensors. The method consists in measuring the time of AE wave blocks passing to individual sensors. Sensor distribu-tion for determining defect location on a flat surface is shown in Fig. 2, and more sensors are applied for larger structures. Sensors can be distributed on structural surface randomly since each has its own coordinates and independ-ent observation zone.

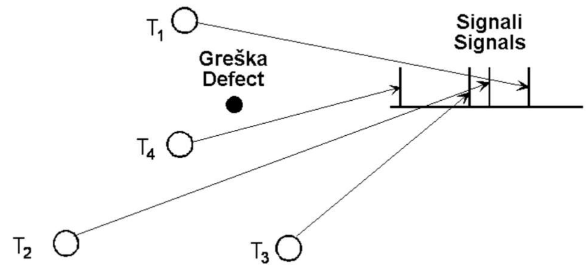

Figure 2. Typical distribution of sensors for determining defect location on a flat surface.

Although they can give more data about tested material state, other AE signal processing methods are rarely used due to the complex equipment, not available on the market.

In laboratory conditions, the defect location is often known when testing material by AE method. An example is testing of precracked specimens for fracture mechanics parameters determination. Block scheme of this testing is given in Fig. 3.

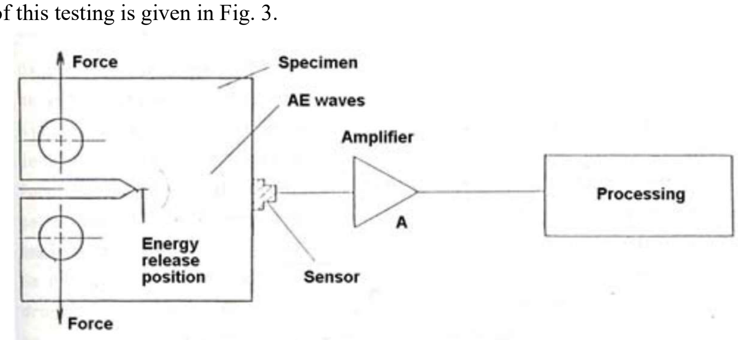

Figure 3. Block scheme of the system for detection and acoustic emission signal processing in testing a precracked specimen, [2].

When the specimen is loaded to yield stress the condition for further crack growth is met and it becomes the AE signal source. AE signal processing in this case should offer as much as possible data to link it with parameters and values describing the same event.

4. APPLICATION OF ACOUSTIC EMISSION

Most important field of acoustic emission application is testing of materials, welded joints, and structures. By testing metals and composites acoustic emission contributes to mechanical property characterization and determination of fracture mechanics parameters. Acoustic emission can be used in welded joint quality control. It is possible to detect defects by acoustic emission during manufacturing compo-nents and structures, and to determine occurrence of stress corrosion cracking and defect location, and monitor active defect behaviour during operation.

The most significant advantage of acoustic emission compared to other NDT methods, the ultrasonic method in particular, is the possibility to detect the defect in material without detailed and full examination of its surface. This reduces the possibility of undetected defects in material and reduces the necessary testing time, [5].

Diagrams obtained by testing mechanical properties of smooth specimen composite carbon fibre (fastener) – epoxy resin (matrix) are given in Fig. 4. Elongation is presented on the abscissa, and load *F* on the ordinate (diagram I) and acoustic emission AE (diagram II). The left figure is a failure due to delamination, and due to a void in the matrix on the right. Negligible AE can be seen in the elastic range, and more active at onset of plastic deformation.

Results of precracked specimen tests are presented in Fig.5. Crack opening displacement (COD) is on the abscissa, and load *F* (diagram I) and acoustic emission AE (diagram II) on the ordinate, presented by magnification 30× (signal amplification) for better analysis. One can also notice here that there is no acoustic emission in the elastic range and that it is rapidly intensified with stepwise crack growth, the "saw tooth" segment on diagram I.

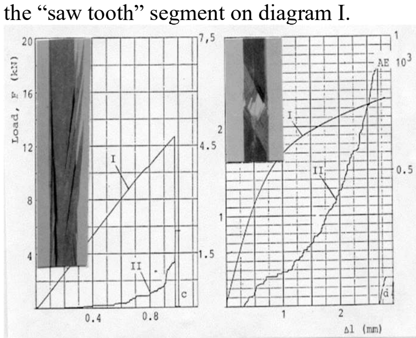

Figure 4. Diagrams of smooth specimen tests of composite carbon fibre – epoxy resin, /5/.

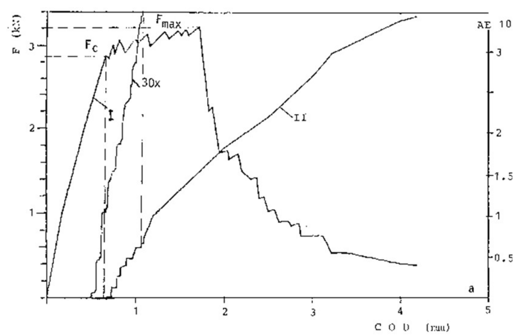

Figure 5. Diagrams of precracked specimen tests of composite carbon fibre – epoxy resin, /5/

Damages in composite materials can occur already at low stress. Basic mechanisms generating AE signal in com-posites are fibre fracture, cracking of the matrix, phase delamination, fractured fibre relaxation, interlaminar crack development and increased stress concentration.

Pressure vessel testing by acoustic emission is of special significance since the behaviour of material and welded joints caused by variation of the pressure during cold proof test and in service can be continuously monitored by proper location of sensors and AE processing. This is suitable if the location of detected defect is determined.

An example of acoustic emission testing of pressure vessel is an installed system for continuous monitoring during operation of spherical ammonia storage tank TK-4101 (Fig. 6) at Azotara Subotica. The in-service monitor-ing programme included continuous monitoring of detected cracks behaviour.

Ultrasonic inspection of welded joints RI (100%), RII (100%) and RIII (15%) detected outer side cracks. According to their size, form and location in the welded joint they represent locations where deformation or crack growth may be expected.

Indications marked as 1/1 and 2/5 are continuously monitored (Fig. 7). Parameters of first measurement with the AE sensor counter adjusted to zero were taken as refer-ence. Prior to monitoring a calibration curve was made for the material (microalloyed steel ASME A 516 Gr. 70) used in manufacturing the spherical storage tank. This curve is used to define elementary signals for plastic deformation and crack growth, and based on them acoustic activity was defined with high decision level for possible deformation process and implications in the material, in order to allow the acoustic emission sensor to register them.

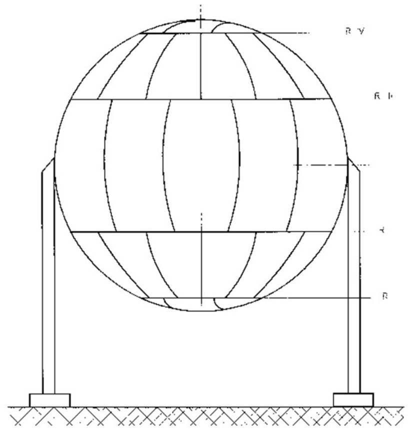

Figure 6. Spherical storage tank for ammonia TK-4101.

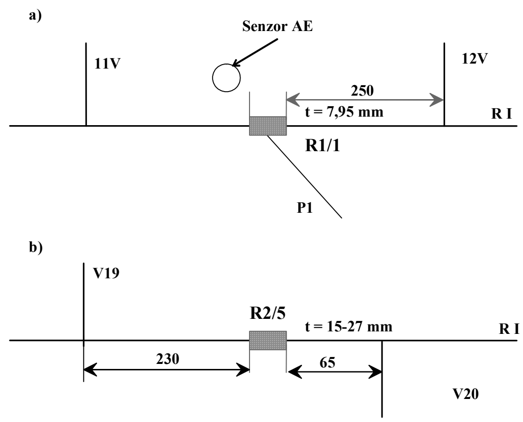

Figure 7. Scheme of locations for continuous monitoring.

The acoustic emission sensor is located close to the crack indication 1/1 (Fig. 7). It is connected via coaxial cable to AE detector located in sphere control desk room. Processing of AE signal is based on counting oscillations registered by sensor. This method is selected based on gath-ered experience and the possibility to use adequate equip-ment for AE signal monitoring and processing.

In a period of one month intensive acoustic emission ac-tivity is recorded by detector as a consequence of frequent pressure changes in the spherical storage tank. Pressure was changed by discharge and filling of the tank and through change in outer temperature. It is experimentally confirmed that change of temperature in the tank also means change of pressure. Typical acoustic emission vs. time diagrams for the test period are given in Fig. 8 on dates 21.03–22.03. and in Fig. 9 on 22.04–23.04.

Figure 8. Diagram of acoustic activity vs. time

Figure 9. Diagram of acoustic activity vs. time

Very small change in acoustic emission in Fig. 8 indicates elastic deformation and a negligible level of plastic deformation. Stepwise increase of oscillations (Fig. 9) recorded by sensor was most probably a consequence of fatigue crack growth due to variable pressure after certain level of plastic deforma-tion that can cause leakage to occur. This is confirmed by ultrasonic test where crack growth is discovered according to scheme in Fig. 10. In fact, in approximately one month service time, crack depth has increased for about 0.4 mm. However, the crack front increased almost twice (from 30 to 60 mm), and the total crack surface more than doubled.

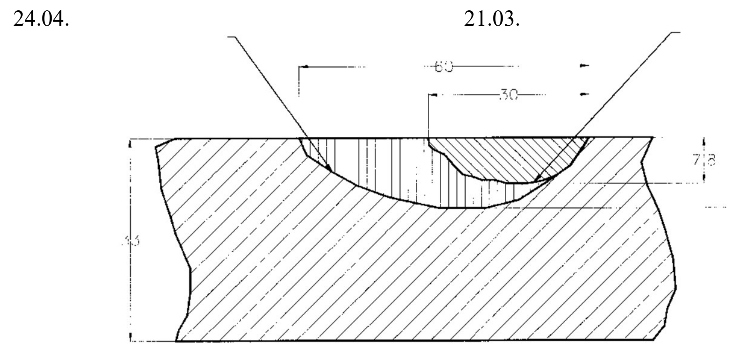

Figure 10. Scheme of crack development at measuring location 1/1.

The behaviour of cracks in the spherical storage tank TK-4101 was continuously monitored by applying the AE method in service, where the effectiveness of acoustic emis-sion as an active NDT method was confirmed by early detection of the deformation process, i.e. formation of plas-tic zone ahead of the crack tip and growth of existing crack. In the presented case the obtained results confirmed its mean-ingful application and indicated critical crack behaviour.

5. CONCLUSION

Presented results of acoustic emission application as an active NDT method confirmed its wide possibility in defect detection what recommends broadening its use for material and structural tests. Acoustic emission is successfully applied in determining characteristics of different materials, including complex structures as in composites. The application of acoustic emission in laboratory tests of materials can contribute to better understanding of loaded material behaviour, also in conditions of crack initiation and growth using fracture mechanics. Acoustic emission method deserves a special place in testing welded structures, being applicable both during and after welding.

6. REFERENCES

[1] Williams, R.V., (2014)Acoustic Emission, Adam Hilger Ltd, Bristol.
[2] Burzić, Z., (1989),Primena akustične emisije za praćenje parametara mehanike loma kod kompozitnih materijala (The application of acoustic emission for monitoring of fracture mechanics para-meters in composite materials), Magistarski rad (Master degree thesis), TMF, Beograd.
[3] Beattie, A.G., (2010)Acoustic Emission a Brief Survey of Instrumentation Techniques and Applications, Material Evaluation 34, p. 73.
[4] Brindley, B.J., Holt, J., Palmer, I.G., (2012)The Use of Ring-down Counting, Non-destructive Testing 6 , p. 299.
[5] Burzić, Z., Sedmak, S., Mitraković, D., Zrilić, M., (1989),Application of acoustic emission for monitoring fracture mechanics in com-posite materials, AECM-3, p. 422-431, Paris, France.
[6] Burzić, Z., Aleksić, B., Arsić, S., Vujović-Đorđević, B., Maravić, M., (1997),Primena akustične emisije i tenzometrijskih ispitivanja na praćenje deformacijskog procesa na sfernom rezervoaru (The application of acoustic emission and tensometry testing to monitoring of deformation process in spherical storage tank) Zavarivanje i zavarene konstrukcije, Vol. 42, No. 3, str. 225-233, Beograd.