# 1 Introduction

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## 1.1 AET in the Context of Other Techniques

AET is considered quite unique among the non-destructive testing methods, what starts with the question of whether this method should be classified as completely non-destructive or not, since fracture of the material is necessary for testing. In contrast to other NDT methods, however, AET is usually applied during loading, while most others are applied before or after loading of a structure. Following these arguments, and according to the way in which the signals are recorded, AET is correctly described as non-destructive. The statement is certainly true if a material is tested under a working load without any additional load. On the other hand, AE is often used to detect a failure at a very early stage, long before a structure completely fails.

A more dominant attribute to distinguish the different NDT techniques is addressing the way the technique is applied and sort of information that can be obtained. The ultrasound method, for example, is able to detect the geometric shape of a defect in a specimen using an artificially generated source signal and a receiver, whereas the AET detects the elastic waves radiated by a growing fracture. Therefore, the acoustic emission (AE) method should be considered to be a "passive" non-destructive technique, because it usually identifies defects only while they develop during the test. AE is often used to detect a failure at a very early stage of damage long before a structure completely fails. **Fig. 1.1** illustrates the idea behind the terms “active” and “passive” in NDT. In essence, the source emitting the waves is generally applied to the material in active methods (**Fig. 1.1**, top) using for example scanning techniques, whereas, in the passive methods, the sources are within the material (**Fig. 1.1**, bottom); they quasi “produce” the test signal. These characteristic features of the AE method result in advantages as well as disadvantages that will be addressed in the next section. However, the nature of the signals usually being recorded should be described first in more detail.

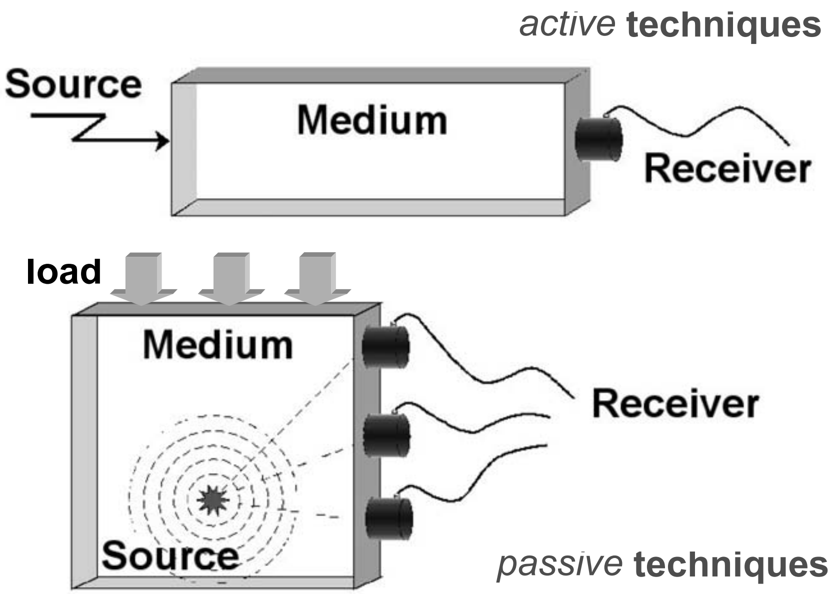


**Fig. 1.1.** Comparison of NDE principles using active or passive techniques.

The sources of acoustic emissions can have widely varying characteristics due to significant differences in the source signals. These differences get more pronounced using non-resonant transducers and after separating signals from noise, which can arise from artificial or natural sources with origins inside or outside the tested object. Continuous emissions, produced for instance during metal cutting or by friction in rotating bearings (Miller and McIntire 1987), show very different signal characteristics when compared to burst signals caused by the spontaneous release of energy during cracking (**Fig. 1.2**). Monitoring of continuous acoustic emissions can be used to control the operation of machines, although it is often difficult to localize the source of the emission. Most techniques used in the AET are better suited for burst signals and therefore will generally be addressed in the following chapters.

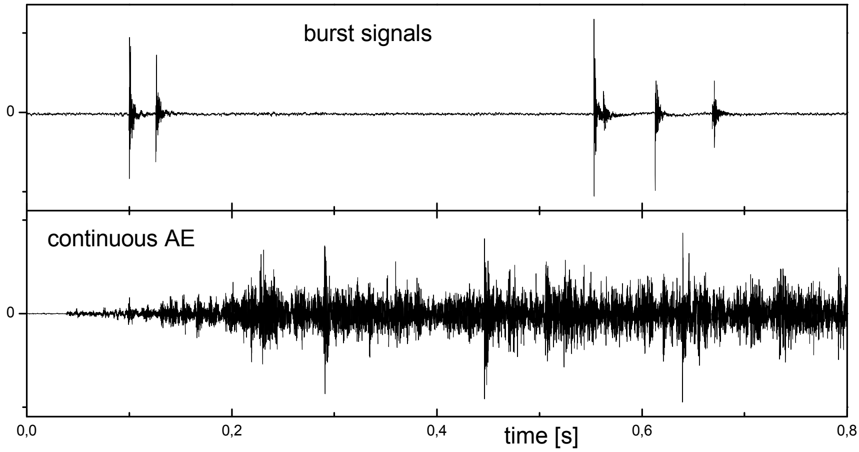


**Fig. 1.2.** Example of burst signals compared to a continuous emission of acoustic waves.

## 1.2 Advantages and Disadvantages of AET

An advantage of AE techniques, compared to other non-destructive testing techniques, is that damage processes in materials being tested can be observed during the entire load history, without any disturbance to the specimen. Ultrasonic analysis techniques, for instance, have to be applied in conjunction with scanning techniques to detect a defect. They usually require stopping the loading of a structure. In contrast, AE studies require under favorable conditions only a few sensors being able to monitor the AE activity of a structure, provided there are sufficiently strong signals to cross a threshold called trigger level. The sensors can be fixed to the surface of the specimen for the duration of the test and do not have to be moved for scanning the whole structure point by point. Access to both sides of an object, which is necessary for all through-transmission methods, is not required in AET.

The stress field in the specimen being tested is related to the applied force. When a material is stressed, the deformations are controlled by what is known as the constitutive behavior of the material. For example, some materials respond to stress linear elastically, and others behave elasto-plastically. The linear elastic stress-strain relationship is called Hooke's Law. AE however, are more strongly dependent on the irreversible (non-elastic) deformations in a material. Therefore, this method is only capable of detecting the formation of new cracks and the progression of existing cracks or friction processes. These phenomena are often related to internal mechanical or thermal loads or pressures applied from outside the specimen. AE tests can be conducted under normal, service conditions or during a slight enhancement of the load. Therefore, it is extremely useful in testing structures under real load conditions to record a possible failure process.

A disadvantage of the AET method is that a particular test is not perfectly reproducible due to the nature of the signal source, e.g. the sudden and sometimes random formation of a crack. Although specimens of the same shape and same material properties should cause similar AE activities under load, this is not always the case. Materials with scattered inhomogeneities of a particular dimension, such as concrete, will not give similar AE results if the wavelength of the signals is of a similar size as the heterogeneities. This is one of the reasons why it is useful to compare the results of acoustic emission tests with other testing methods, for example using a visual inspection of the surface or ultrasound methods, X-Ray or RADAR.

Another point addresses the energy released by an acoustic emission. Signals – in particular those used as precursors of failure – are usually several magnitudes smaller compared to signals used in ultrasonic techniques. This requires much more sensitive sensors as well as reliable amplifiers and pre-amplifiers. Problems related to this are the influence of ambient noise, the attenuation of signals and the probably resulting low signal-to-noise ratio. It requires sophisticated data processing techniques to detect acoustic emissions, to localize them and to apply other advanced techniques or inversions.

A reliable analysis of acoustic emission signals and the interpretation of the data in material testing are usually only possible in cases where the signals have been localized successfully. Signal localization is the basis of all analysis techniques used in AE, and the various methods will be described in detail in Chap. 6. Before the localization topic is dealt with, however, a short characterization of the way acoustic emissions are recorded will be given. Knowing how signals are recorded is essential in understanding the AET in general, and also provides insights into interpreting the results.

## 1.3 Acoustic Emission in Context to Seismology

An earthquake is a sudden movement of the Earth's crust that generates elastic disturbances, known as seismic waves. These waves propagate spherically outwards from the source, as a result of transient stress imbalances in the rock, and vibrate the ground. These vibrations can cause damage at the earth's surface, which can be correlated to the magnitude of the earthquake and the local geological conditions.

Several large magnitude earthquakes, that destroyed huge areas and caused many deaths, are well remembered in human history. The San Francisco earthquake in 1906, for example, (**Fig. 1.3**) radiated waves that were recorded as far away as Germany. The waves are physical waves and can be recorded by instruments called seismometers, which record ground motion. The recordings of ground motion as a function of time are called seismograms. An example of seismograms of the San Francisco earthquake, recorded by a seismometer in Germany, some 9100 miles (ca. 14600 km) from the earthquake source is shown in **Fig. 1.4**.

**Fig. 1.3.** Earthquake damage in San Francisco after the 1906 earthquake.

Acoustic emissions (AE) can be considered to be a form of microseismicity generated during the failure process as materials are loaded. AE is defined as the spontaneous release of localized strain energy in stressed material. This energy release can be due to, for example, microcracking in the material and can be recorded by transducers (sensors) on the material's surface. This is the reason why AET are so similar compared to seismological techniques – they basically address the same concept but at a different scale. Far-field seismology investigates earthquakes in a distance of thousands of kilometers, near-field seismology in distances of several hundred kilometers. Acoustic emission techniques are usually applied for source-receiver distances of up to several tenth meters, but specimen can also be much smaller down to even millimeters. However, applications in the range in between the given distances (i.e. 10 to 100 meters) are sometimes called micro-seismology and sometimes large-scale acoustic emission analysis. It is simple to see the similarities of these techniques based on signal interpretations looking at the earthquake recording in **Fig. 1.4** and comparing it to acoustic emission recordings in the following chapters of this book. The basic difference concerns the scale of the time axis.

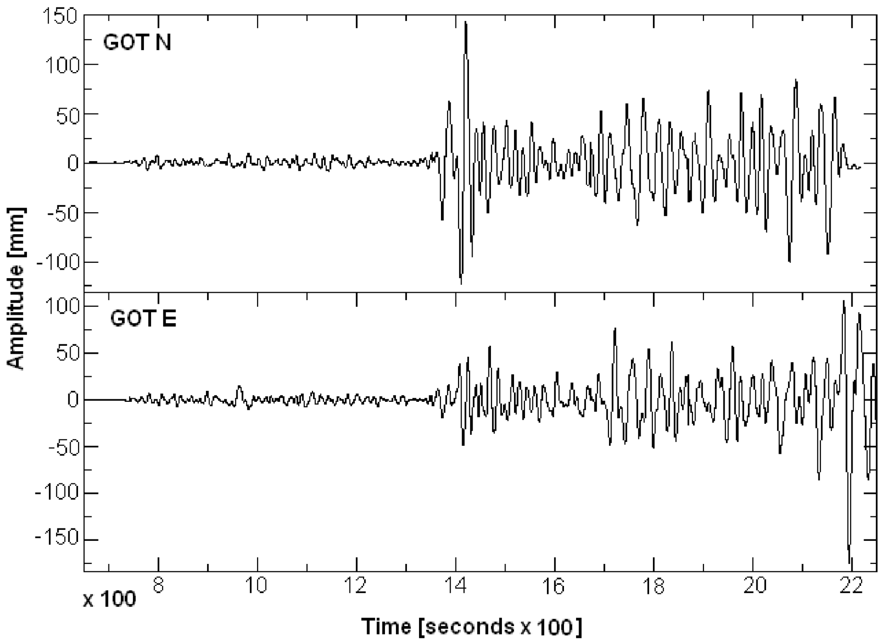


**Fig. 1.4.** Seismograms of the 1906 San Francisco earthquake recorded in Göttingen, Germany, some 9100 miles away from the earthquake source; (top) NS components, (bottom) EW component (from Wald et al. 1993).

Seismological data are usually analyzed on the basis of their full waveform or of a significant part of this (in **Fig. 1.4** are only the first 22 seconds shown). In acoustic emission this was not always the case and is probably still not the case for many applications. Historically speaking, former recording techniques based on very basic electronic components were simply not able to handle the large amount of high frequency data. This led to the workaround to extract parameters out of the waveforms that were afterwards not recorded what means they were not converted from analog to digital data. The parameter-based approach will be described in detail later. Some successful parameter-based AET applications used to study for example cementitious materials can be found in the literature (McCabe, Koerner et al. 1976; Notter 1982; Feineis 1982; Reinhardt and Hordijk 1989; Kapphahn 1990; Sklarczyk, Gries et al. 1990). Some authors began in the late 1980's and in the early 1990's with the theoretical development of quantitative techniques based on waveform analysis (Scruby 1985; Sachse and Kim 1987; Ono 1993). A point motivating these developments was the interconnection between AE and seismology. Seismological techniques were adapted for example for civil engineering by some authors (Ohtsu 1982, 1994; Ouyang et al. 1991; Ohtsu et al. 1991; Maji and Sahu 1994; Maji 1995). Ono and Ohtsu have been probably some of the first scientists transferring earthquake data processing techniques to AE data processing. The basic for these advances are developments in microelectronics and in computer-based analysis techniques. AE is usually dealing with high signal rates and events at relatively high frequencies (from 20 kHz up to several megahertz). Recording and analysis devices need powerful techniques to handle these data. It is remarkable that even sophisticated techniques such as the three dimensional localization of events, the moment tensor inversion or wavelet techniques are nowadays routinely applied in the AE environment and it is expected that other methods will stimulate further developments.

New developments raise new problems. However, the demands on the equipment are still very high. This is particularly true concerning the sensor technology. Resonant transducers are increasingly replaced by sensors with broader frequency characteristics. Issues of flat response, sensitivity and calibration have to be addressed more carefully in the future. Other sensor techniques that are currently discussed in the field of AE applications (e.g. in structural health monitoring) use network techniques, wireless communication and Micro-Electro-Mechanical Systems (MEMS). These promising ideas ensure that the acoustic emission technology will be a field of interesting future developments and applications.

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