The Acoustic Emission Testing: A Promising Tool for the Health Structural Monitoring of the Compressed Gas Cylinder Fully Wrapped with Composite Materials

Salah RAMADAN 1, Slah YAACOUBI 1 and Daniel CHAUVEAU 2

1 Institut de Soudure Recherche et Enseignement, RDI-CND, Espace Cormontaigne, 4 Blvd Henri Becquerel, 57970 Yutz, France; s.ramadan@institutdesoudure.com, s.yaacoubi@institutdesoudure.com, tel. +33 3 82 88 79 52, fax. +33 3 82 88 86 45.

2 Institut de Soudure Industrie, Fellow CND, ZI Paris Nord 2, 90 rue des Vanesses, 93420 Villepinte, France; d.chauveau@institutdesoudure.com, tel. + 33 1 49 90 37 32, fax. + 33 1 49 90 79 35.

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Abstract

Composite materials have important assets compared to traditional metallic materials. They have many functional advantages and enhanced mechanical properties. Nowadays these engineered materials are employed in aerospace, aeronautical and transport industries. In spite of their advanced mechanical properties, the structural health of these materials must be controlled in order to insure their durability and functionality. Specific damages affect composite’s health during manufacturing process or in their lifespan e.g. porosity, discontinuity of carbon fibres, fibers pull-out, matrix cracking, carbon fibres rupture, delamination…

In service, the assessment of the presence of flaws is the control key point of the composites’ robustness and reliability. Accordingly, the identification of the various early weakness mechanisms by a Non Destructive Testing (NDT) proves a great importance in order to guarantee the safety and the use of composite.

To answer this problematic, the NDT by Acoustic Emission (AE) was proved to be well adapted. In the present work, AE has been used to monitor in real time Compressed Air Breathing Apparatus type 4 cylinder, made of a plastic liner and fully wrapped with a carbon-fiber composite. Experimental results have shown the capacity and the sensitivity of AE to detect the local internal changes in the composite’s structure.

Introduction

Composite materials are engineered materials made of two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.

Since its introduction, many years ago, the use of composite materials in various industries is still evolving. These heterogeneous materials fulfilled the industrial requirements in terms of durability and reliability. Moreover, they offer interesting properties in comparison to traditional materials such as: rigidity, lightness, freedom of form… Composites are considered today as young materials and they reached their age of industrial maturity. Many defects can affect them and could consequently limit their viability. Most harmful are those which appear in their service life such as: ruptures of fibres, matrix cracking...

A lot of industrial structures made of composites are in service since at least thirty years. In order to ensure their durability and functionality and to guarantee their staff safety, they require to be regularly controlled. The traditional method used to quantify the component is the hydraulic test which is often problematic. Unfortunately, it may cause the stop of the plant exploitation which is relatively costly. In addition, the method forces the plant to be subjected to 1.5 of its Operating Pressure (OP). Consequently, additional risks of ageing can affect structures
lifespan. With the advance of technology, the Non Destructive Testing (NDT) can replace this method. For a few decades, academic research has been focused onto the identification of the damage mechanisms of the composite by using NDT methods [1-4]. Some experiments have been made to utilize X-ray radiography and ultrasonic testing but because of the inherent industrial limitations of these methods and the complex nature of composite damage mechanism, this has not been very successful [5-9]. Acoustic Emission technique (AE) is an additional NDT process that offers the ability to detect flaws evolution as it appears in glass-epoxy or carbon-epoxy composites [10-12].

Few studies reported the application of the AE to monitor wrapped composite vessels, tanks or compressed gas metal cylinders [13, 14]. The control of the industrial glass-epoxy tanks by AE attracts the attention, particularly in the United States since 1982 (CARP procedure, Committee on Acoustic Emission from Reinforced Plastics). Several standards control for the evaluation of these structures are already worked out [15, 16]. Nevertheless, the control of the high pressure storage tanks made of carbon-epoxy is still at the development stage. Studies in this field have to be doubled in order to work out a standard control methodology for carbon-epoxy vessels or tanks.

The objective of this present work is to study the possibilities offered by AE in terms of control of the high pressure composite gas cylinder and to rule on these limitations.

The results have shown the relation between acoustic activity evolution and pressure variation of the compressed cylinder. Emissive sources have been identified and correlated with internal local modifications in the bottom of composite structure.

Material

Internal pressure tests with acoustic emission monitoring have been performed on a Compressed Air Breathing Apparatus type 4 cylinder, made of a plastic liner and fully wrapped with a carbon-fiber composite. The standard size of the wrapped cylinder is of 6.8 liter operating at 4350 psi (see Fig. 1).

Four compressed cylinders were tested during their filling of air until their OP. Each test comprised a stage of maintenance at OP during 4 minutes. The filling rate was approximately about 725 psi/min.

![AE monitoring system](https://example.com/image.jpg)

Fig. 1: Compressed gas cylinder fully wrapped with a carbon-fiber composite used during this study.
Acoustic emission system monitoring

AE instrumentation consisted of an AMSY5 system developed by Vallen® society. Four wideband piezoelectric transducers, 2 VS 150-RIC and 2 VS 375-RIC, with integral preamplifier (namely S1, S2, S3 and S4) were used. The preamplifier gain was about 34 dB_{AE}. The sampling frequency for data acquisition was 10 MHz. In order to eliminate external noise, two frequency filters were used: a low pass filter with a cut-off frequency of 25 kHz and a high pass filter with a cut-off frequency of 850 kHz.

On the one hand, the threshold acquisition value was fixed, according to the measurement of the RMS recorded during the preliminary tests before the pressurization cycle, on the other hand, taking into account the ambient noise. The acquisition threshold was fixed at 40 dB_{ae} for all tests. No parametric filters were used during AE data acquisition. All signals with a count number lower than 1 were removed.

The S1 sensor was positioned at 2 cm of the higher part of the cylinder (see Fig.1). The S2 sensor was placed at 25 cm from the higher part of the tank, on the composite surface. S3 and S4 sensors were set respectively on the superior and inferior base plates of the cylinder.

A auto-calibration and a Hsu-Nielsen (2H-0.3 mm) tests were carried out before and after the pressurization/depressurization cycles in order to allow a functional verification of the measuring system as well as for the constancy of the sensitivity for the complete length of the follow-up time.

Results and discussion

Analysis of the acoustic activity during pressurisation cycles

Figure 2 represents the evolution of the acoustic activity vs. time during the first pressurization cycle of the composite cylinder. At low pressures, the acoustic activity was very weak. The salves reached firstly the S1 and S2 sensors. At the beginning, S3 and S4 sensors were less sensitive. The amplitude of the signals recorded for this probation period test was between 40 and 75 dB (see Fig. 2c). From 725 psi, the S4 sensor became more sensitive compared to the S1 and S3 sensors. Increasing pressure enhances the acoustic activity. When the pressure reaches the operating pressure value, the acoustic activity becomes steady.

Indeed, during the stage of pressurization cycle, the expansion of the compressed air inside the liner exerts an important pressure on the composite structure which generates a significant acoustic activity. Another hypothesis could be used to explain this acoustic activity, the rupture of weak carbon fibres at the bottom of the composite… The stabilization of this activity at the operating pressure seems to be related to the absence of evolutionary defects in the structure and to the reduction of the expansion phenomenon of the liner. The discriminated acoustic signature (see Fig. 2) during this test could be used as a basis for future tests in order to differentiate the acoustic events related to a damage mechanism from those coming from the internal modifications within the composite (expansion of the liner, contact liner/composite…).

The preliminaries results showed the sensitivity of the AE technique with respect to the detection of the internal modifications within the controlled structure. The evolutionary phenomenon generate acoustic activity. Growing defects would generate a detectable acoustic noise. On the other hand, is it possible to locate it? If necessary what it will be the measurements’ exactitude? It is well-known that composite materials take up and attenuate ultrasonic waves which distort sometimes the localization. Moreover, the composites are emissive and their damage mechanism is rather complicated. Several sources of damage can superimpose such as: delamination, rupture of fibres, matrix cracking, etc those complicate more the localization. Future tests will have to answer these questions in order to test the technique in an industrial site and to work out a methodology of control.
a) Hits number vs. time.

b) Hits number vs. channels.

c) Amplitude vs. time.

d) Duration vs. time.

e) Energy vs. counts.

f) 3D plot energy/counts vs. time.

Fig. 2: Evolution of the acoustics parameters vs. time during the pressurization cycle of the composite gas cylinder.

Fig. 3: Waves forms recorded by S1 (a) and S2 (b) sensors during the pressurization cycle of the composite cylinder, respectively, and their spectral density.
Analyze of the acoustic activity during depressurisation cycles

The depressurisation of the cylinder produces a powerful acoustic activity of about 21000 hit/channel (see Fig. 3a and b). Recorded hits were energetic with high duration values (see Fig. 3c and d). Indeed, the exhausts of the compressed air as well as the relaxation of the liner are at the origin of this activity. Moreover, the acoustic signature recorded during this test should be used as a basis for future tests in particular to isolate noisy signals from those coming from a damage mechanism.

Fig. 4: Variation of the acoustics parameters vs. time during the depressurization cycle of the composite gas cylinder.

Conclusion

The follow-up of the compressed composite gas cylinder by acoustic emission highlighted:
- The sensitivity of AE with respect to the detection of any local internal modifications within a composite structure (expansion and/or liner relaxation of the liner, exhaust of the compressed air...)
- The capacity of the method in the checking of the integrity of the gas cylinder.

Supplementary analyses are necessary for a better classification of the acoustic data in order to discriminate an event coming from a noise of that drifting of a damage mechanism.

Additional tests have been carried out in order to verify the ability of AE to monitor in real time industrial compressed gas cylinder fully wrapped in composite. Preliminary results are very interesting and could help to define a control methodology in industrial site.
References