DOI: 10.5075/epfl-ICSS12-2018-118-120

LOCALISATION OF DAMAGE TO A ROTOMOULDED PE SANDWICH STRUCTURE BY ACOUSTIC EMISSION SUBJECTED TO INTERNAL PRESSURE

Eric Lainé[1], Anne-Laure Gorge[2], Maxime Cruz[3], Jean-Claude Grandidier[4], Eric Maziers[5], Geert Vaes[6] and Simon Karam[7]
[1]Institut Pprime, CNRS, ISAE-ENSMA, Université de Poitiers, F-86962 Futuroscope, France, eric.laine@ensma.fr
[2]Institut Pprime, CNRS, ISAE-ENSMA, Université de Poitiers, F-86962 Futuroscope, France, anne-laure.gorge@ensma.fr
[3]Institut Pprime, CNRS, ISAE-ENSMA, Université de Poitiers, F-86962 Futuroscope, France, maxime.cruz@ensma.fr
[4]Institut Pprime, CNRS, ISAE-ENSMA, Université de Poitiers, F-86962 Futuroscope, France, jean-claude.grandidier@ensma.fr
[5]Total Research & Technology Feluy, Zone Industrielle Feluy, B-7181 Seneffe, Belgique, eric.maziers@total.com
[6]Total Research & Technology Feluy, Zone Industrielle Feluy, B-7181 Seneffe, Belgique, geert.vaes@total.com
[7]Total Research & Technology Feluy, Zone Industrielle Feluy, B-7181 Seneffe, Belgique, simon.karam@total.com

1. INTRODUCTION

Sandwich materials are increasingly used in industrial applications. They generally consist of two thin skins of relatively high tenacity materials and a thicker lightweight core (low density). These sandwich materials can take many shapes by combining different skin types (aluminium, steel, wood, polymer, composites...) and core materials together with different geometries (honeycombs (aluminium, polymer, Nomex), cellular foams, balsa...). This makes it possible to produce optimal sandwich materials for specific applications. Generally, the mechanical behavior of these sandwich structures (skin-core-skin) is determined by bending tests (3 or 4 points) and impact tests (weight drop) in both static and dynamic modes. In literature, many works are devoted to the determination of the damage on these sandwich materials using the technique of acoustic emission (AE). For example, Burman et al. [1] studied the initiation and progression of damage in cellular foam sandwich composites. The acoustic characteristics of mode I and mode II on PVC foam fracture were determined by both single notch and end notch bending tests. Ben Ammar et al. [2] studied the mechanical behaviour under static (4-point bending) and dynamic loads and also evaluated the damage of two types of sandwich composite materials. However, there are very few articles in the literature on EA for sandwich polymers. One reason may be that polymers strongly attenuate ultrasonic waves and are less energetic. However, acoustic emission was used to analyze plastic deformation and damage in pure semi-crystalline polymers [3,4] above their glass transition temperature and vitreous polymers (PET) [5-6]. If a very low acoustic activity was observed [3,4], Ronkay et al. [6] attribute the signals to the formation of cavities, which appear with propagation through the neck during tensile tests. Recently, Casiez et al. [7] showed for two types of PE samples that AE can be sensitive enough to analyze the initiation of plastic deformation, including cavitation, on semi-crystalline polymers above their glass transition temperature. The challenge is to verify that this technique (AE) is able to apprehend damage in a polymer sandwich material. This is the purpose of this paper. Beforehand, tensile tests have been carried out on PE material at different constant strain rates and our results are consistent with those of Casiez et al. [7]. A static test on a rotomoulded PE sandwich structure (bottle) subjected to increasing internal water pressure is carried out up to an acoustic level sufficient to develop damage without failure of the structure (external skin). The acoustic activity of this instrumented test appears to agree with the observed structural damage.

2. SANDWICH MATERIAL (SKIN-FOAM-SKIN) AND SANDWICH OR MULTILAYER STRUCTURE (BOTTLE)

Researchers from one of the WW major Oil company 'Total' have developed a new sandwich material consisting of a foamed polyethylene (PE) layer between two PE skin layers. The PE skins and foam have a density of 0.935 g/cm^3 and 0.200 g/cm^3 respectively. The structure (bottle) is made by rotational moulding, a polymer conversion technology specifically designed to produce hollow plastics parts. This type of sandwich material (skin-foam-skin, Figs. 1(a) and 1(b)) dramatically increases the stiffness for the same weight.

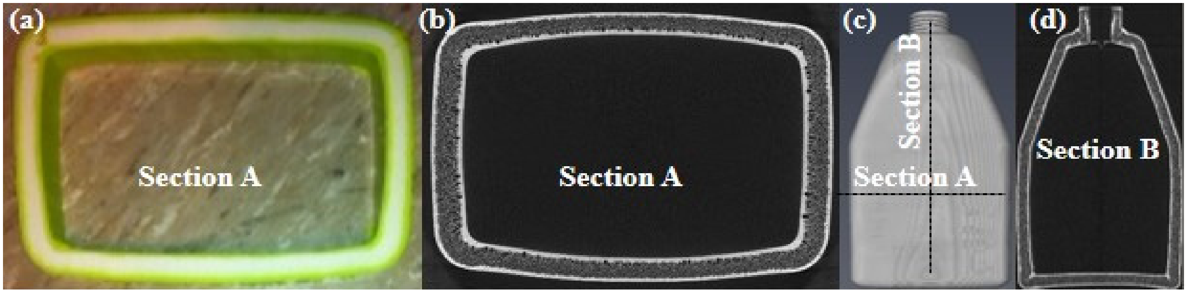

Fig. 1 : Sandwich material: (a) photo and (b) tomography of a bottle section - Sandwich structure: tomography of (c) the bottle and (d) a section.

This new technology offers the opportunity to use lightweight polyethylene in structural parts which is interest particularly for the automotive, aeronautical, storage and transport industries. The sandwich structure used in this study is a multilayer bottle with dimensions: height 330 mm, width 200 mm and depth 140 mm (Figs. 1(c) and 1(d)). The PE skins and foam have a thickness of 2 and 10 mm respectively. This is a reference test structure for the company Total. It is used during the development of new materials to define and optimize the processing parameters, to extract specimens for a thermo-mechanical characterization and to perform tests under different loading conditions (creep ...).

3. EXPERIMENTAL PROCEDURE

The experimental test bench ENDOMAT (Fig. 2(a)) implements a mechanical testing machine including tensile-compressive (1200 kN) and internal pressure (1200 bars). The axes impose stress loads in static and dynamic possibly synchronized over a frequency range up to 10 Hz according to the amplitude of monitored efforts. The useful dimensions of the testing machine are (700x700x1800 mm) with a volume of 882 L allow fastening large-dimension structures on the bench test. As of the pressure axis, it has two devices in parallel, each transforming the hydraulic power into oil to the hydraulic power circuit and into water in contact with the structure to be tested. The first is a transfer accumulator (oil or water) that transfers the pressure supplied by the oil circuit with a storage tank (hydraulic operating pressure: 300 bars). The second device is a booster which multiplies the pressure by four thanks to the piston surfaces. The system can convert the oil operating pressure from 300 bars to 1200 bars in the water circuit, but at a lower rate. A specific assembly (Fig. 2(a)) has been developed to connect the bottle to the test bench, allowing positioning, maintenance and sealing during an internal pressure test. With this system, the bottle can be loaded with mechanical compression and internal pressure in different ways: monotonous, load-unload, creep, fatigue (cyclical). In addition, it is possible to couple mechanical compression and internal pressure simultaneously.

An 8-channel Express System Mistras is used to record AE signals during bottle testing (Figs 2(b)-2(e)). The test is carried out with eight "micro80" piezoelectric acoustic sensors with a PAC 1220A preamplifier with a gain of 40 dB. The peak sensitivity of the sensor is approximately 450 kHz for pressure waves and 250 kHz for Rayleigh (surface) waves. The signals are digitized with a sampling rate of 5 MHz. The sensors are fixed with silicone and attached to the bottle by tape strips. They are positioned in a "triangle" (Fig. 2(b)-2(e)) to locate the acoustic signals as well as possible because the localization system works by calculating the time difference of the acquisition of a wave for two different sensors. When recording AE signals, the user sets a detection threshold (32 dB) below which no signal is recorded. The acquisition system is calibrated before each test using the mine breakage procedure [8].

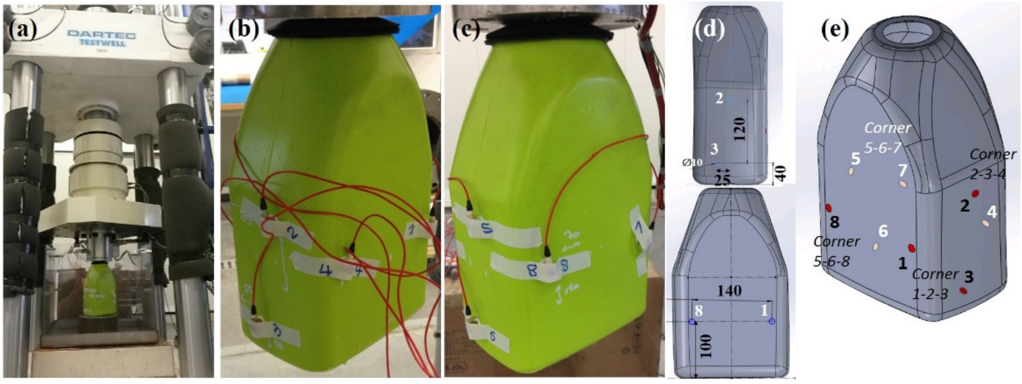

Fig. 2 : (a) Endomat and Specific assembly, (b) - (c) - (d) & (e) Bottle equipped with EA sensors and Position of EA sensors.

4. RESULTS AND DISCUSSIONS

A test with monotonous loading under internal pressure was carried out. The objective was to interrupt it when the acoustic activity would become high without the complete break on the bottle. Thus, from 6 bar pressure (Fig. 3(a)), the AE signals increase rapidly (Fig. 3(a)) mainly on sensors 1, 2 and 3 (Figs. 2(b)-2(e)), a very low activity on sensor 6 is observed and no activity is detected on sensors 4, 5, 7 and 8. When disassembling the structure, it can be observed that the inner skin of the bottle displayed several large cracks (Fig. 3(b)). The AE signals detected by sensors 1, 2 and 3 appear to correspond to damage in the inner skin at the vertical edge and the two horizontal edges (Fig. 4(a)) framed by these three sensors. On the other vertical edges, no damage is observed, which may explain why the other sensors (4, 5, 7, 8) did not detect any signal. It is not possible here to distribute the signals perceived by the sensors in relation to the damaged areas. However, it is certain that the signals are weak that sensor 6 (Fig. 3(b)) has detected damage to the horizontal edge of the bottle bottom (Fig. 4(a)). The crack is only 10mm long. Finally, it is likely that the signals perceived by sensor 1 correspond to the damage to the vertical edge (breaking length approximately 110 mm) but also to the two horizontal corners (1 and 2) of the bottom of the bottle which have a crack length of 80 and 70 mm respectively. Fig. 4(b) shows the AE signals count (N) and amplitude (V) obtained during the static internal pressure test. The data at $N \geq 5$ was plotted, since a few AE signals were generated due to the swelling process. The AE signals count (N) and amplitude (V) verify the following relationship where A and m are constants (Fig. 4(b)). This correlation corresponds to a crack growth during the test [9]. The value of the parameter m is equal to 1.88 (Fig. 4(b)). This one is close to that determined by Yamabe et al. [10] for rubber material (*m*=1.8) under the static crack growth test on classical specimen (for metal material, *m*=2 [11]). Fracture behaviour is correlated with this slope; consequently the value obtained for this polymer material is representative of crack growth of an energy which is between steel and rubber [10].

The use of AEs for polymers such as PE allows tracking, damage and/or structural failure. These results are definitively complementary to the work of the literature [3-7]. The passage from a tensile specimen to an industrial sandwich structure is therefore validated. In a complex environment (pressurized water), using this PE sandwich structure, it is possible to detect the first stages of damage at 6 bar and the propagation of cracks up to the high breaking stage of the inner skin with acoustic emission. It seems that only one mechanism is captured by AE in the ruin process.

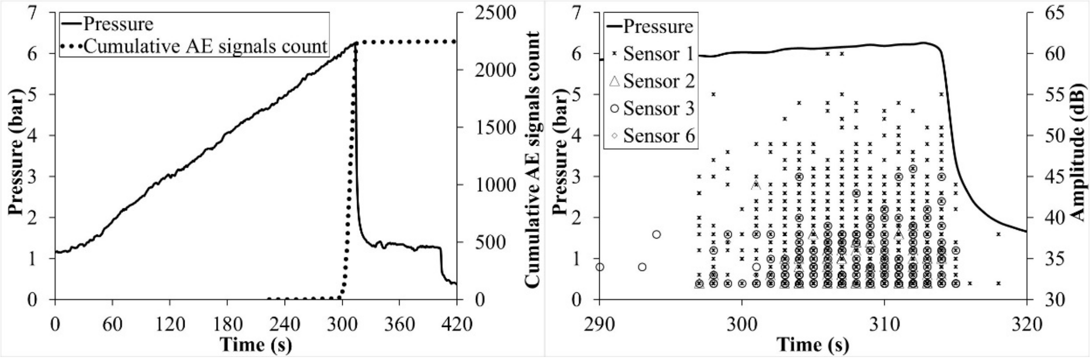

Fig. 3 : (a) Pressure vs. Time and Cumulative AE signals count vs. Time, (b) Zoom of Fig. 3(a) between 290 and 320s - Pressure vs. Time and AE amplitude vs. Time.

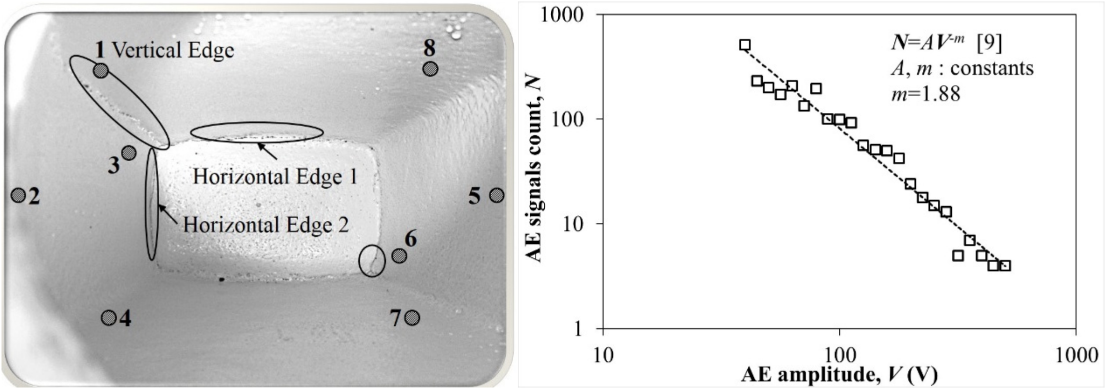

Fig. 4 : (a) Photo of the inside of the bottle after testing and disassembly – (b) Relationship between AE signals count and amplitude obtained from static pressure test.

ACKNOWLEDGMENTS

This work was funded by the French Government program "Investissements d'Avenir" (EQUIPEX GAP, reference ANR-11-EQPX-0018). The authors would like to thank Total Petrochemicals for their financial support for this research and for the provision of structures (bottles).

REFERENCES

[1] M. Burman et al., "Acoustic Emission Monitoring of Foam Core Sandwich Composites", *J Sand. Struct. Mat.*, 1999; 1:147-175.
[2] I. Ben Ammar et al., "Mechanical behavior and acoustic emission technique for detecting", *App. Acoustics*, 2014; 86: 106-117.
[3] J. Bohse, "Acoustic emission characteristics of micro-failure processes in polymer blends and composites", *Compos. Sci. Technol.*, 2000; 60:1213-1226.
[4] R. Qian et al., "Acoustic emission during stretching of polymers, *J Polym Sci* , 1983; 2:168-175.
[5] D. Betteridge et al., "Analysis of acoustic emissions from polymers", *Polymer*, 1983; 24:1206-1212.
[6] F. Ronkay et al., "Cavity formation and stress-oscillation during the tensile test of injection molded specimens made of PET", *Poly. Bull*, 2006; 57: 989-998.
[7] N. Casiez et al., "Acoustic emission from the initiation of plastic deformation of Polyethylenes during tensile tests", *Polymer*, 2014; 55: 6561-6568.
[8] K. Jemielniak, "Some aspects of acoustic emission signal pre-processing", *J. Mat. Proc. Tech.*, 2001; 109: 242-247.
[9] M. Ohtsu, "The history and development of acoustic emission in concrete engineering", *Mag. Conc. Res.*, 1996; 48: 321-330.
[10] J. Yamabe et al., "Application of acoustic emission method to detection of internal fracture of sealing rubber material by high-pressure hydrogen decompression", *Poly. Testing*, 2011; 30: 76-85.
[11] S. Yuyama et al., "Effect of environmental, mechanical conditions, and materials characteristic on AE behavior during corrosion fatigue processes of an austenitic stainless steel", *Nucl. Eng. Des*, 1984; 81: 345-355.