Ultrasonic guided waves for reinforced plastics safety

Slah Yaacoubi[1], **Lynda Chehami**[2], **Marwen Aouini**[1] and **Nico F. Declercq**[2]

[1] Institut de Soudure, 4 Bvd Henri Becquerel, 57970 Yutz, France
[2] Georgia Tech Lorraine, 2 R Marconi, 57070 Metz, France

The application of ultrasonic guided waves (UGW) to the field of preventive maintenance of composite structures is in continuous increase. Today, UGW is taking an important economical place, especially in the fields of transport and nuclear technology, where the safety of individuals is of higher importance than financial cost.

Ultrasonic guided waves and composites

UGW are mechanical waves that propagate along an elongated structure while guided by its boundaries, such as a tube, a plate, a bar, a rod, a rail, etc. Commonly, these waves are generated at frequencies above the range of human audible frequencies (i.e. 20 kHz), the reason for which they are qualified by 'ultrasonic'. Thanks to their capacity to travel along a long distance with little loss in energy (in some cases more than one hundred meters), their use is nowadays largely sought, especially for the inspection of metallic pipelines, vessels, cables and metal plate structures.

Generally, to test such a structure, two possible sensing measurements can be used, as shown in Fig. 1. In the pulse-echo measurement, the transducer plays a dual role: emitter and receiver. Alternatively, in pitch-catch measurements, two transducers are needed, and should be placed on either side of the area to be tested. This arrangement may not be suitable in testing context because it needs baseline data, which are not easy to get in most cases. Nonetheless, it is very useful in structural health monitoring SHM (i.e. sensors are attached to the structure to be monitored and live permanently with), and can be complementary to the pulse-echo arrangement when a defect cannot undergo an echo strong enough to be caught by the actuator/sensor.

During their propagation in the wall of a structure, these waves can interact with defects, if any. The acquired signal either in pulse-echo or in pitch-catch measurement arrangement should be impacted by the presence of damages. The most relevant features are to be extracted from the collected signals to run with the integrity of the structure at hand. Figure 2 (left) shows a numerical simulation based on the finite element method of how the interaction of one mode with a defect in a plate may cause reflection and modal conversion. This simulation is intended simply to give an indication: the result depends on the material and the thickness of the structure in which UGW propagate, and the excitation source characteristics such as its shape, its size, its frequency band, and also the characteristics of the sensor, particularly in experiments.

From an industrial point of view, application of this technique on composite structures is much more complicated than on metallic structures, where UGW are developed for over 20 years. This is due to two main reasons, where the first is linked to the nature of the composite material as such, and the second is due to the type of defects that can occur in a composite structure. Composite materials, this includes reinforced plastics, are in general anisotropic (i.e. directional variability of the mechanical properties) non-homogeneous and high attenuating to waves (because of the viscoelasticity of the plastics). For illustration, Fig. 2 (right) shows a numerical simulation result case of UGW propagating in an orthotropic composite medium. As it can be seen, distances of propagation (i.e. velocities) as well as UGW amplitudes are not omnidirectional. As a main consequence, damage localization is not a straightforward item in practical cases. It should be noted that the localization of damage is as important as its detection. Indeed, if composites are damaged, it is economically and ecologically attractive to repair them rather than reject and replace, without being at the expense of safety.

E-mail address: s.yaacoubi@isgroupe.com.

0034-3617/ http://dx.doi.org/10.1016/j.repl.2016.12.002

Please cite this article in press as: S. Yaacoubi, et al., Reinf. Plast. (2016), http://dx.doi.org/10.1016/j.repl.2016.12.002

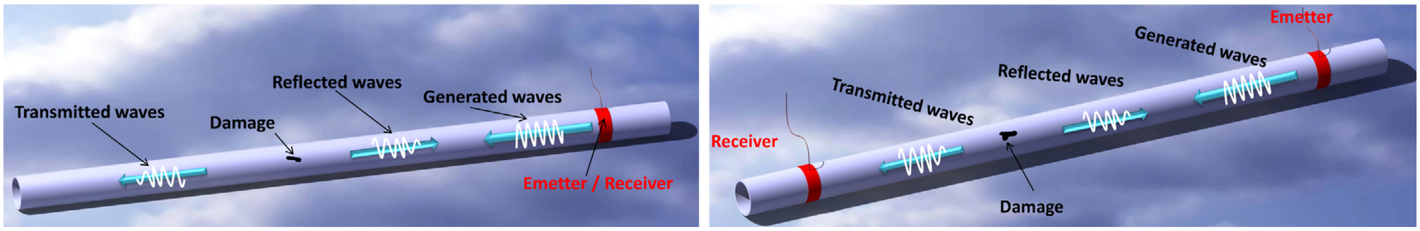

FIGURE 1
Experimental arrangement: pulse-echo (on the left hand-side), and pitch-catch (on the right hand-side).

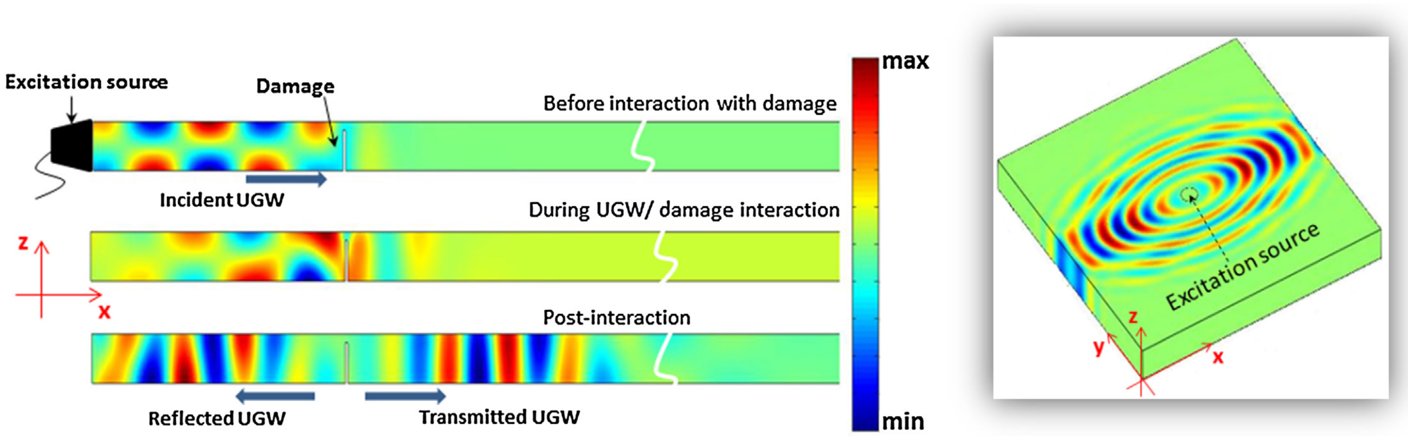

FIGURE 2
Numerical simulations illustrate the influence of the presence of a damage (left), the anisotropic composite material behavior on UGW propagation (right).

Regarding the second reason, damages occur in many different forms such as delaminations, disbonds, porosity, fibers pull-out, fibers fracture, matrix splitting, cracking and micro-cracking or also loss of properties (modulus) due to aging, etc. Some examples of composites defects are given in Fig. 3. Defects can be exterior or hidden, but most of them are hidden, and therefore visual testing (VT) technique is not reliable to run with the integrity of a structure. Various nondestructive techniques, more advanced than VT, are already developed to detect these defects either in post-manufacturing or *in situ*, but most of them are relatively slow and high-priced.

For large composite structures, shearography and infrared thermography are among the techniques that exist nowadays, however their applications are unfortunately limited to surface and underlying damages. UGW can be an alternative tool since they propagate in the core of the structure, with a high capacity of long distances of propagation. This offers the possibility to ensure a rapid and reliable inspection or monitoring. To do so, the technique should be rigorously applied because it is dispersive (i.e. their velocities are generally functions of the structure thickness and the excitation frequency), multi-path and multi-modal (i.e. existence of many possible propagating modes) nature.

As for any testing and monitoring techniques, the detectability of a given defect is a function of its dimensions. In normal usage, UGW technique cannot allow detecting relatively small defects. Nevertheless, in practice, composites are often damage tolerant

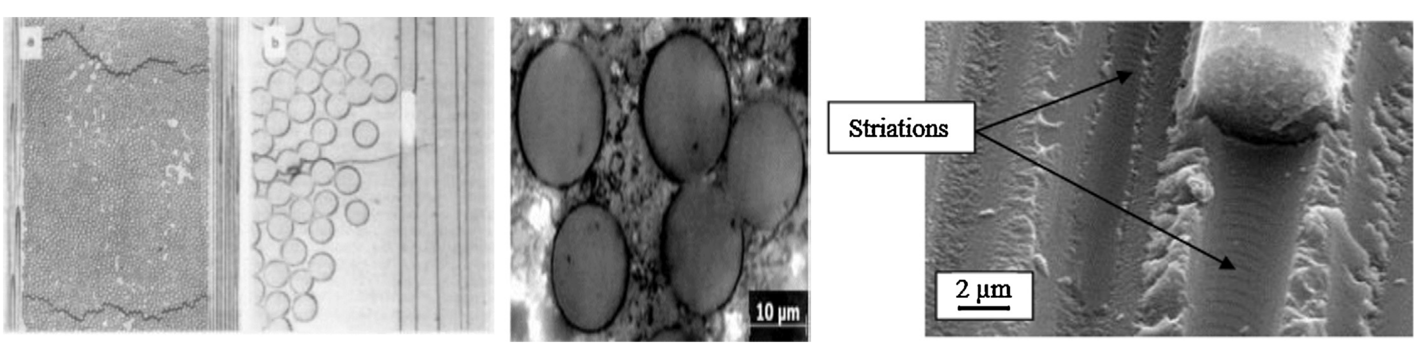

FIGURE 3
(Left) A cross plied FRP laminate, showing non uniform fiber packing and micro cracking [5], (middle) optical microscopic image of fiber/matrix disbonding, (right) fatigue striations due to fracture of fiber/matrix interfaces.

Please cite this article in press as: S. Yaacoubi, et al., Reinf. Plast. (2016), http://dx.doi.org/10.1016/j.repl.2016.12.002