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SMART COMPOSITE STRUCTURES: Benefits, technical issues and potential applications

Currently, in different industrial fields as transport or aerospace, a strong research effort concerns structural weight reduction. Of course, one of the most promising solutions is the use of composite structures. In the same time, there is an intensification of the operational dynamic environment and an increase of durability requirements. The design compromise seems hard to find. One way to manage this point is to design and manufacture composite structures adaptive to their environment: smart composite structures.

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The core of this article will provide an overview of the technical issues for producing smart composite structures. The main manufacturing features are exhibited from a case study concerning a smart automotive spoiler. The manufacturing process used has been developed at the IRTES-M3M laboratory over the past 12 years. It provides an opportunity to design a large set of smart structure applications.

What is a smart composite structure?

First of all, the starting point to define a smart composite structure is to define what a smart structure is. In 1996, Spillman, Sirkis and Gardiner [1] established a definition from a large survey. A smart material/structure is a physical material/structure having:

- A definite purpose,
- Means and imperative to achieve that purpose,
- The pattern of functioning of a universal computer or a biological entity.

The basic components of any smart system have been summarised by Akhras [2]: (*their equivalents in the human body appear in parentheses*):

- Data acquisition (*tactile sensing*): collect the required raw data needed for an appropriate control and monitoring of the structure.
- Data transmission (*sensing nerves*): forward the raw data to the local and central control units.
- Command and control center (*brain*): analyse the data, reach the appropriate conclusion and determine the specific actions.
- Data instructions (*motion nerves*): transmit the decisions and the associated instructions back to the members, and
- Controlling devices (*muscles*): take action by triggering the controlling devices/units.

A smart composite structure is a host structure made of composite material in which the different basic elements described above are embedded. Let's note that, due to its constitution (plies and resin) and its way of manufacturing, the composite laminate is particularly adapted to the integration of

exogenous components into the heart of the material. Indeed, this type of integration can be hardly considered for classical materials in particular for metallic materials. Figure 1 depicts the standard architecture of a smart composite structure.

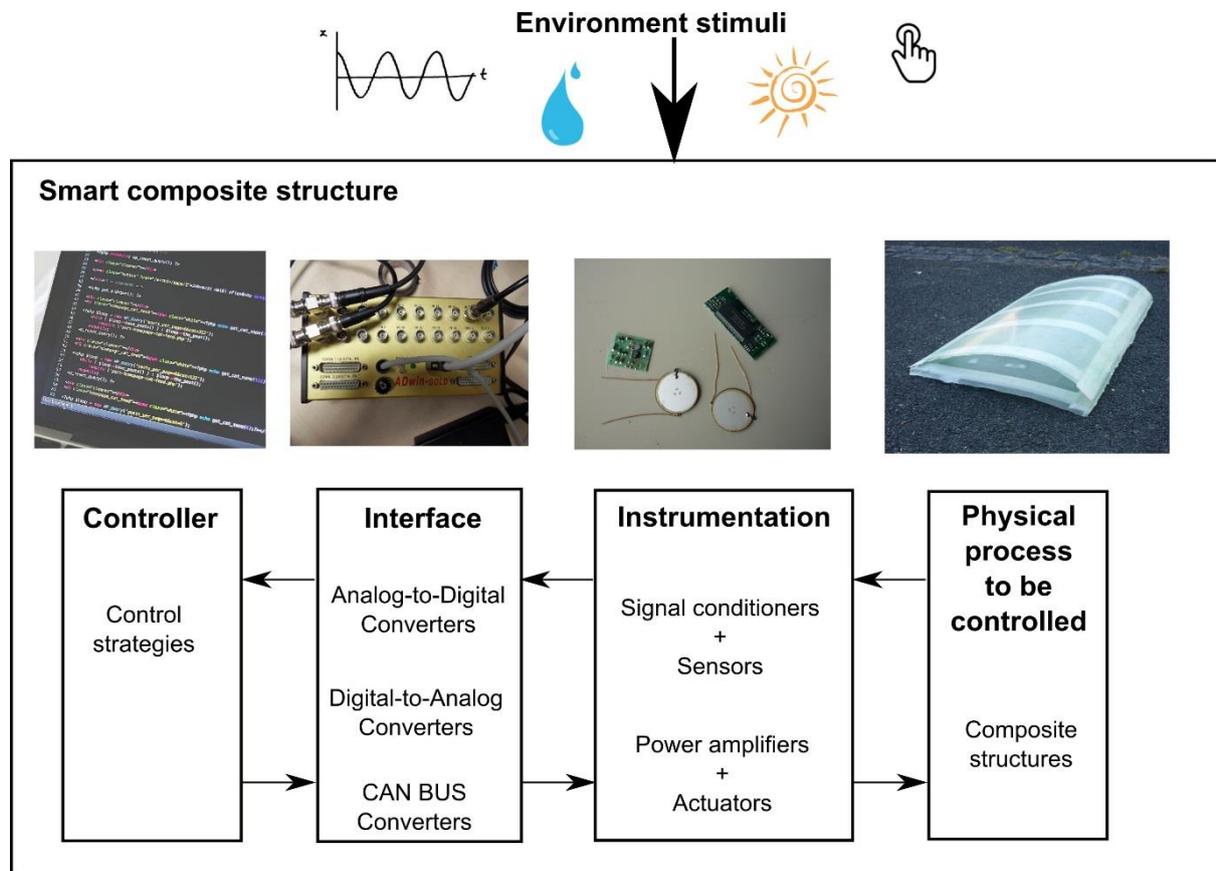


Figure 1: Architecture of a smart composite structure

Case study: a smart automotive spoiler

In the frame of a project funded by the Labex ACTION program, a smart automotive spoiler has been manufactured. This spoiler has to be able to strongly damp the guided waves propagating in the structure. For this, a specific decentralized control is used [3]. Consequently, the technical requirements concerning the composite spoiler are as follows:

- The spoiler length is 1160 mm +/- 1%,
- The wall thickness is 1.8 mm +/- 30%,
- A network of piezoceramic discs is embedded into the spoiler (50 units),
- The transducers are distributed according to an array of 25 transducers in extrados and an array of 25 transducers in intrados,
- The pitches of these matrices are 60 mm +/- 10%.
- Each transducer is electrically independent and insulated from the other ones (100 output wires),
- No local thickness modification is allowed.
- Only 3 transducers can be out of order.

The mould used to manufacture the spoiler was provided by the Espera Sbarro automotive design school. The spoiler consists of fibreglass-reinforced-polyester laminate. It was prepared from 6 plies of chopped strand mat. The matrix is a thermosetting plastic (polyester resin). The used composite

manufacturing process is a Vacuum Assisted Resin Transfer Molding (VARTM). The fibre volume ratio is around 35 %. A blue gelcoat was applied on the spoiler top surface as a finish. Thanks to a dedicated process based on the use of semi-finished products, the piezoceramic discs, the connecting system and the electrical conductor network are embedded between the first ply and the second ply. The first ply is close to the top surface (gelcoat). The 100 wires are carefully-set in position of the same spoiler edge. The final product is shown in Figure 2. Only 2 transducers are out of order after 2 trials of manufacturing.

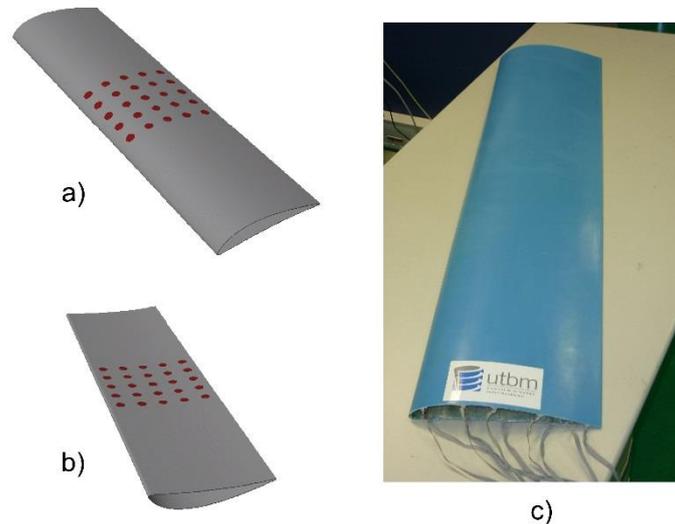


Figure 2: Smart automotive spoiler with 50 piezoceramic discs embedded. a) Extrados and b) Intrados of a CAD picture of the spoiler manufactured (The red spots represent the transducers location). c) Real object

Benefits and technical issues

From this case study, the technical issues and the benefits of a smart composite structure with an embedded network of transducers are exhibited.

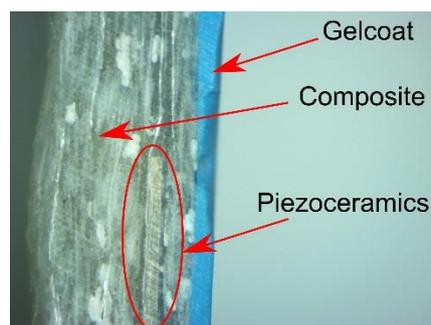


Figure 3: Close-up view of a smart material slice

Conventionally, to create a smart composite structure, the transducers and the electrical conductor network are glued onto the structure to be controlled and the electronics is located outside the structure. Our approach is significantly different. We have exploited the ability of integration given by the composite material. With this process, the idea is to protect the transducing elements and their electrical connections and to industrially develop end products in plug-and-play mode. Furthermore, the integration of transducing elements at the heart of the material is the first step to develop, thanks

to the integration of micro and nano structures, programmable or controllable matter with the ability to modify their intrinsic material properties in real time.

To integrate these new functionalities (in particular, for large structures), it is necessary to develop a real fully distributed set of transducers embedded during the manufacturing process. To guarantee the transducers efficiency and keep the geometrical and material properties of the host composite structure, several major technical issues are identified as having a strong impact on the manufacturing requirements [4]. It is necessary to:

- Electrically connect a large number of transducers so as to act on the whole structure. This is the condition to take advantage of a distributed network. With a distributed control network, it is possible to modify the structural behaviour of a system over a large excitation frequency range or, more generally, over a large multi-physical excitation range.
- Make electrically-independent each transducer. This is a particular issue for the development of carbon-fibre-reinforced composite structures which are naturally conductive. The use of semi-finished products can provide a good electric insulation solution.
- Perfectly couple the exogenous element with the composite material so as to guarantee the transducers efficiency and reduce the risks of delamination or other failures.
- Accurately master the location of the transducers into the structure. This is necessary to create symmetric arrays of transducers and so a highly-symmetric distributed network. This approach can provide advantage in particular to control the guided waves propagating into a thin structure.
- Limit the cross-talk between the different embedded elements. A technical requirement has to be defined in order to set a design rule concerning the minimum pitch between two electrical conductors or the minimal distance between two transducers.
- Limit the thickness variations due to the piezoelectric inclusions. These inclusions inside the material will inevitably modify locally the thickness of the structure. This fact may be limited by the use of thin piezoceramics (about 150 μm). Moreover, the electrical connection by conventional welding is not advised because of the resulting excess thickness and the possibility to create a wedge. Obviously, this wedge can break the piezoceramics during the manufacturing process. Consequently, the transducer is then out of order. A specific connection technique has been developed based on the use of semi-finished products.
- Achieve specific shaped structures (for instance, bi-concave structures) so as to adapt to a wide range of real applications.
- Achieve a robust link with the structure outside to provide energy or modify the control law or the behavioural law in real time.

Currently, the main research efforts concern not only the development of solutions to solve the technical issues detailed above but also the influence of exogenous elements with respect to durability, reliability and maintainability of the host systems. As a response, the first prototypes were manufactured in our laboratory 12 years ago and are always in operation. Of course, this is not a formal proof of a less influence of these elements in system durability and reliability but it is a good tendency. The third point (Maintainability) is a quite complicated item. It is always possible to change an element embedded into a structure with accurate machining operations and matter additions. However, this is not exactly the objective of this type of structures. And so, obviously, strong efforts are necessary to guarantee high durability and reliability.

Another important point to take into account is recycling for the end-of-life products. Of course, some smart composite structures have been manufactured with bio-based materials, as shown in Figure 4.

This is an initial response. The integration of SAW tags could be a solution for tagging of the smart composite structures. Thus, it is possible to create a specific recycling loop. But, the main and essential issue, in particular for mass application, is the way of extracting the exogenous elements from the composite material. Currently, the question is still open. Basically, the compromise level between efficiency and recycling is the key point to prove the industrial validity of this technology.

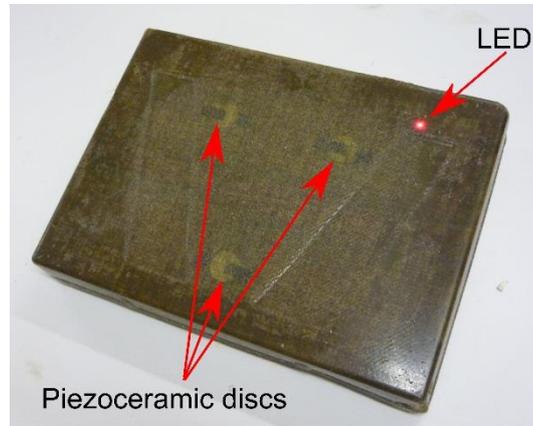


Figure 4: Smart suitcase, made of bio-based material, embedding three piezoceramic discs, an electric resistor and a LED.

Potential applications

Once the manufacturing process and the design approach of smart composite structures will be mastered, it is possible to consider lots of applications in different thematic fields. As examples, four application fields are presented.

Vibration suppress

Mechanical vibrations can have a negative impact on systems [5]:

- Failures can occur by fatigue, by excessive strain during transient events or by instability,
- Vibrations and noise influence customer's comfort,
- In precision engineering (optical systems, machining ...), vibrations limit the operation conditions of the systems.

The smart composite structures can modify their own properties (damping, stiffness, acoustic impedance ...) in order to modify their vibration or vibroacoustic behaviours and so manage the drawbacks detailed above. For instance, it is possible to design a smart composite structure dedicated to the vibration isolation of sensitive electronic components such as the Bulk Acoustic Wave resonators or the inertial platforms.

Structural Health Monitoring (SHM)

Balageas [6] has been defined Structural Health Monitoring as the ability to give, at every moment during the life of a structure, a diagnosis of the state of the constituent materials, of the different parts and of the full assembly of these parts constituting the structure as a whole.

The embedded transducers network can check the quality or the ageing of the host composite structure over a period of time. This network is able to detect a fibre crack or other failures. Associated to micro-controller and specific algorithms, the generated data can be used to locate flaws or to predict the failure event.

Energy Harvesting (EH)

Energy harvesting is a technical method to extract energy from external sources (base vibrations, wind, thermal gradient, sea waves...) [7].

The development of EH devices is in progress for the different types of external sources. In piezoelectricity field, these devices and the technologies used are particularly sophisticated. Thus, it is possible to integrate these EH devices into the composite structure and for instance supply electric energy from vibration energy. Currently, the available electric power is quite limited. But, by distributed network effect, micro-controllers or operational amplifiers could be autonomous and so the overall network too.

Internet of Things (IoT)

The Internet of Things has been defined in [8] as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

By embedding sensors, actuators and communication devices, the connection between physical and virtual worlds is possible. Of course, the preliminary step is to master the recycling of these smart composite structures and in particular the way of extracting the exogenous elements.

Looking forward

Our research team is continually in contact with industrial companies in order to test our manufacturing processes of smart composite structures to their needs and develop new approaches or solutions. Experience has been capitalised on this set of contracts and collaborations to fully develop our skills and propose a large solutions catalog.

Currently, the core of our investigations concerns producing an early stage design approach. From overall technical requirements, the idea is to be able to predict the final behavior of the manufactured smart composite structures. For this, systems engineering tools, knowledge-based models and specific experimental testing are used [4, 9].

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More information

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