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Printed electronics for the functionalization of composite parts

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Abstract
New customers' needs for increased product performance as well as price competition between materials have brought about the need for "smart composites", i.e. multifunctional structures integrating electronic components. Printed electronics is a well suited technology to achieve this goal, as it enables the seamless integration of the electronic functions in the composite structures. An application through a small-scale wind turbine blade has been developed integrating both Structural Health Monitoring (SHM) and de-icing. Since retention of primary structural performance is a major stake, characterization of model composites with film components has been performed.

1. Introduction

1.1 A case for smart composites

In the effort to decrease transportation means' emissions, composites are appraised for their high specific resistance and design freedom allowing for 15-40% mass reduction in a large array of market sectors. However, in spite of the introduction of new materials and processes, composite solutions still lack competitiveness against their metal counterparts in some applications. Making composites "smart", i.e. adding new functions with in-process integration, is therefore a way to improve their overall economic balance and open new opportunities. Moreover, the heterogeneous structure of composites offers new possibilities for electronic architectures and functional integration.

1.2 Needs for multi-functionality

The main staked for the industry are the safety and the efficiency in systems' operations. The present study is based on two main functions integrated in a blade.
The first feature is a Structural Health Monitoring (SHM) system based on six strain gages that will help detect potential damages on the part and also give an overall view of operating conditions. SHM is a way for improved safety but also reduce costs by promoting a predictive maintenance approach instead of periodic visits.
The second targeted function is de-icing.
To monitor the operation of the wind turbine, strain measurement within the blades allows for real-time surveillance to detect unusual events that may occur during the turbines' lifetime. Besides, ice formation makes the blades heavier and may reduce the efficiency of the installation; this is why a de-icing function is needed. However, additional functions should come with as little impact on mass and design as possible. Printed electronics brings here a huge advantage thanks to thin-film components and the possibility to integrate several devices in a single layer.

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2. Experimentation

2.1 Product approach

The supporting use case for the study is a smaller-scale blade with a length of 1m (see Figure 1). Given a pre-study of mechanical constraints in the blade as well as expected thermal specifications, the constitutive materials were chosen as follows:

- A glass-fibre multi-axial (0/+45/-45) reinforcement (areal weight: 1200 g/m²)
- A high-Tg epoxy ("HTG180").

Figure 1: CAD overview of the model blade

The electronics' medium is a polyimide film (thickness: 50µm) on which were printed six strain gages, three temperature sensors and a heating element.

The impact of film introduction in the laminate has been evaluated through flexural tests both in static and fatigue modes. A representative sequence for the actual product was used based on a symmetrical stacking sequence but with the insert out of middle plane:

- [-45/+45/0]
- Polyimide film
- [0/+45/-45]
- [-45/+45/0]
- [0/+45/-45]

2.2 Static 3-point bending test

The first characterization was led under static loading on a Zwick 1485 dynamometer according to NF EN ISO 14125 standard under conventional laboratory conditions (23°C / 50% HR) as seen on figure 2.

- Testing parameters:
- Displacement measurement: « Multixtens » extensometer
- Test speed: 2 mm/min
- Pre-load: 10 N
- Span length: 20 x h
- Support radius: 5 mm
- Anvil radius: 5 mm

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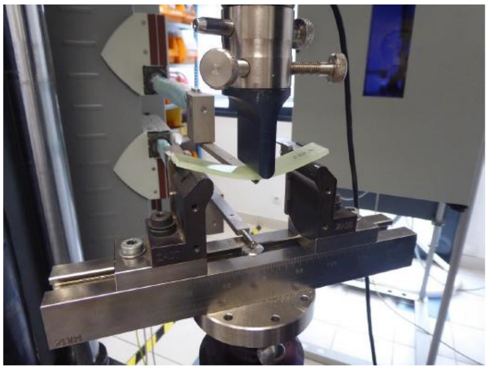

Figure 2: view of test bench

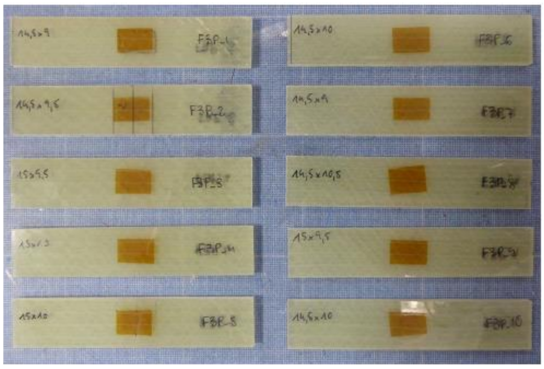

Figure 3: initial samples

Moulding of specimens was made by the infusion process. In test samples, 20 mm x 10 mm polyimide inserts were integrated in a similar way as when components are added in a specific zone of the part.

2.3 Fatigue 3-point bending test

To characterize more precisely the impact of potential weakness at film-composite interface, preliminary fatigue tests have also been conducted on an “Epsiflex” machine. Specimens were similar as in static testing and test frequency was of 5 Hz. The evaluation has been performed over 500 000 cycles.

3. RESULTS

3.1 Static tests analysis

Ten reference samples and ten specimens with inserted polyimide “component” were tested (see figure 4).

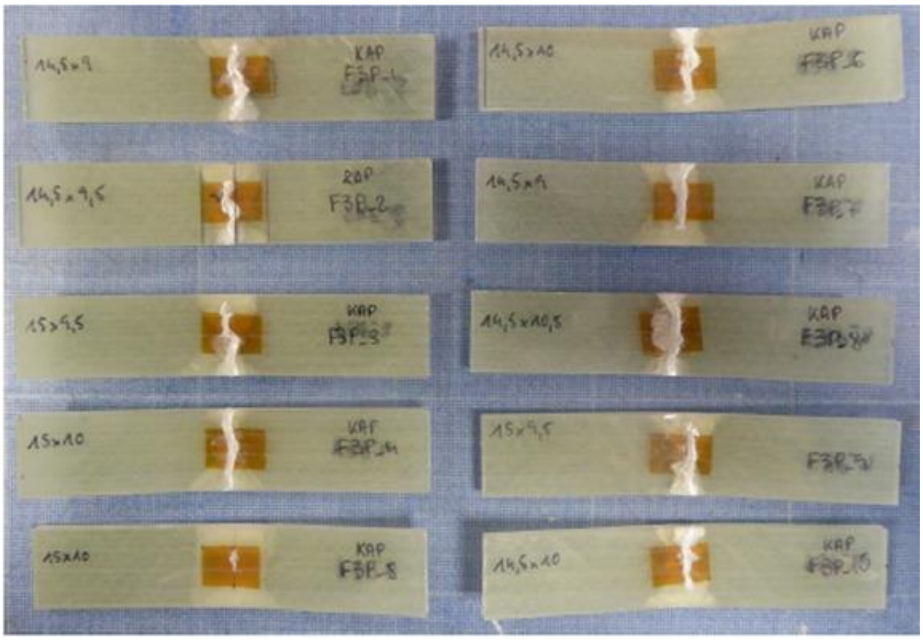

Figure 4: samples after testing

Both configurations show similar stiffness (figure 5): the mean value is 4% higher for the samples with inserts compared with the reference. The impact of film insertion on this aspect is rather little partly thanks to the limited thickness of the added component.

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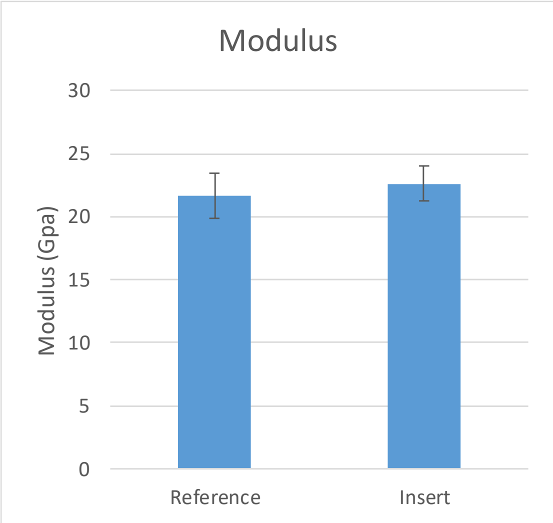

Figure 5: stiffness comparison

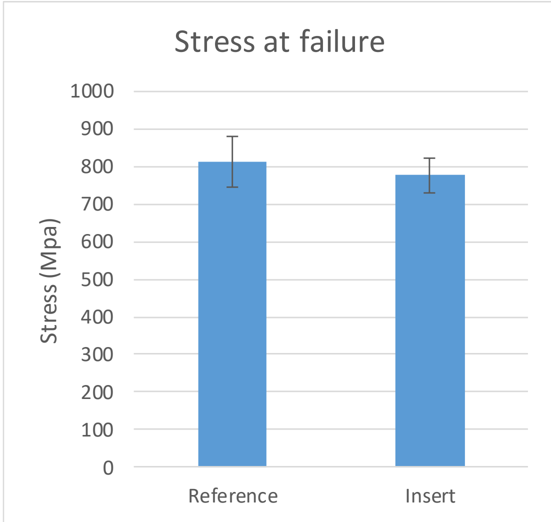

Figure 6: strength comparison

The failure occurs both in tensile and compression modes; delamination was also observed on the reference samples. Still, the equipped samples show no sign of delamination at the film-composite interface which shows a rather good adhesion. This is confirmed by the comparison of the resistance (figure 6) with a stress at failure being only 3% lower for the composites containing a film component.

This results seem to show that properties are maintained when integrating a component in the composite. The adhesion at the film-composite interface is a major parameter for the final mechanical performances.

3.2 Fatigue tests analysis

Preliminary fatigue testing included characterization of a reference sample without film and a sample with a polyimide insert. Displacement was imposed and resulting force was measured. Figure 7 shows the evolution of normalized stress vs number of cycles.

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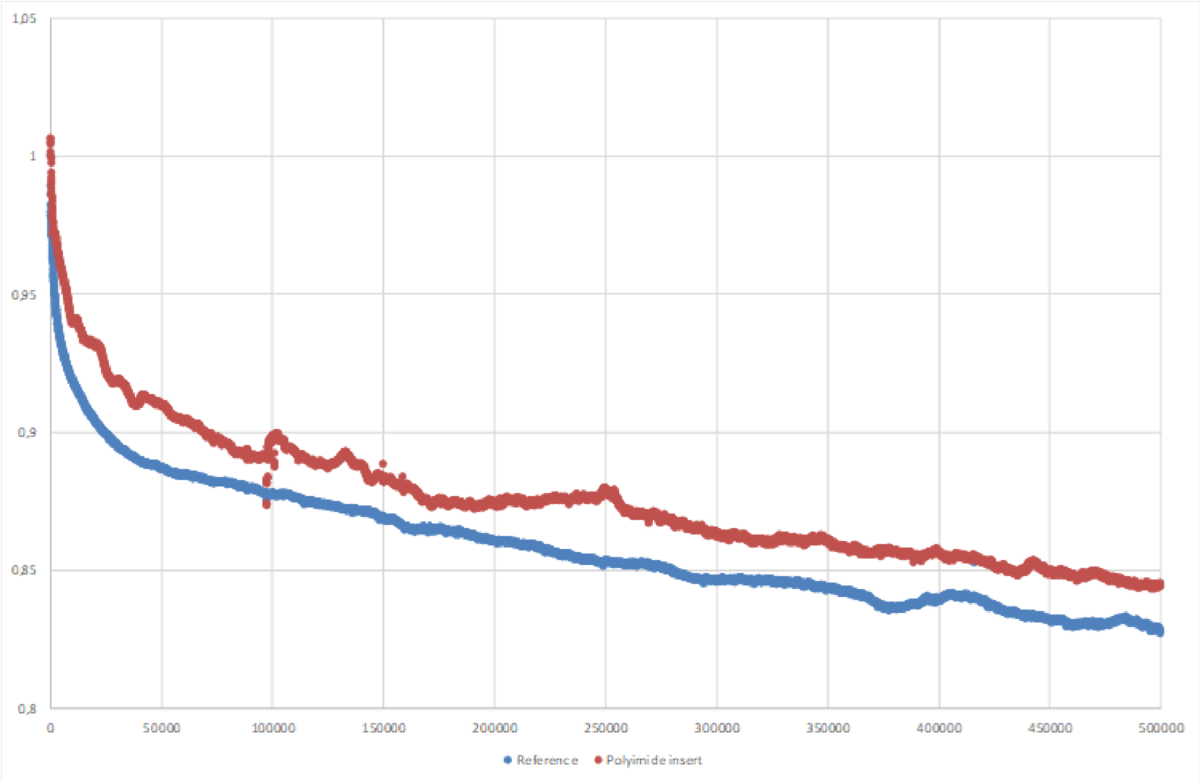

Figure 7: fatigue curves

The comparison of constraints shows that resistance loss is quite similar for the two samples. Still, evolution of resulting force is less regular for the sample with polyimide insert. This could be explained by some heterogeneities in the composite either at the composite-film interface or by defects created during the injection phase due to flow modification in the presence of the insert.

However, these trends must be confirmed by repeating these trials on more specimens.

4. APPLICATION

As mentioned in part 1, the application for integration of printed electronics is a smaller-scale wind turbine blade. Half blades have been manufactured through an infusion process (figure 8) with the fully-equipped film being directly integrated during the process with specific techniques to allow for the interconnection of the component with the acquisition and control systems. Then, the two parts were assembled to obtain the final part (figure 9).

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Figure 8: infusion process

Figure 9: overview of blade part and acquisition/control system

Thanks to the use of a functional film, ten individual components were added in a single step (see figure 10): six strain gages, three temperature sensors (one not shown on figure) and a heating element.

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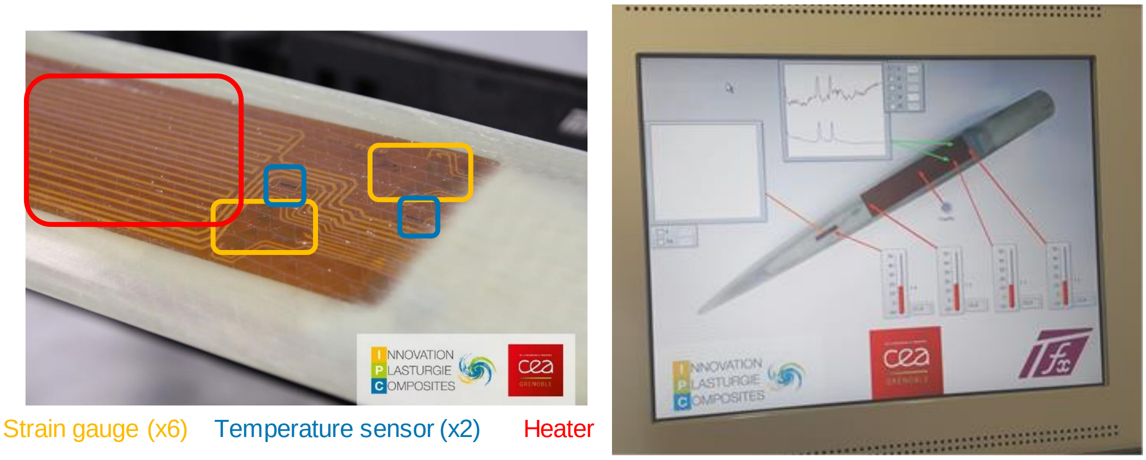

Figure 10: component's description and interface display

This demonstration part shows the potential of printed electronics to define and implement a complex array of functions while minimizing the impact of the process. Another advantage of this technology is its flexibility since changes in the design of the electronics are easier to take into account.

5. CONCLUSIONS

Smart composites help to meet new markets' needs while bringing added value and competitiveness to the composites industry. Printed electronics is a flexible way for multi-functional integration.

Mechanical characterization shows that the introduction of a film component comes with little impact on the structure performance both under static and dynamic loading. This can be achieved thanks to low ratio between respective film and laminate thicknesses and a good film-composite interface.

The application of this technology in a small-scale wind turbine blade shows the potential for industrial implementation.