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DYNAMIC IN-SITU MEASUREMENTS OF 3D COMPOSITE MATERIAL MECHANICAL CONSTRAINTS DURING THE WEAVING PROCESS.

Trifigny Nicolas [1,2], Boussu François [1,2], Koncar Vladan [1,2], Soulat Damien [1,2]
1 Univ. Lille Nord de France, F-59000 Lille, France;
2 ENSAIT, GEMTEX, F-59100 Roubaix, France;
francois.boussu@ensait.fr

Abstract: The purpose of this project is to record the mechanical stress spreading along the warp and weft yarns during the weaving process. Fibrous sensors previously developed in our laboratory have been used to measure mechanical strain directly on fabrics. [1][2]. The objective of our research work is to develop new yarn sensors compatible with the weaving process and sufficiently resistant and able to locally detect the mechanical stress all along the damaged yarn. This local detection is realized during the weaving in real time inside the weaving loom. Suited electronic device are designed in order to record in situ measurements delivered by this new yarn sensor.

1. Introduction

Aircraft industry, and Jet engine manufacturers in particular, have to meet the new environmental requirements and regulations set up by the worldwide authorities. One of the most important issues is the weight reduction of carriers, particularly in some critical moving parts like turbines of Jet engines, in order to reduce the fuel consumption. In the new generation of aircrafts a certain number of metallic parts have to be replace by composite materials with the same resistance and lower weight. These composite materials need also to be safe in order to maintain their performance all along their lifetime. Thus, composite materials using fibrous reinforcement have to be produced by the manufacturing process that has to be monitored all along the production cycle in order to minimize the tow damages and increase the mechanical performances.

In order to obtain optimal performances (mechanical and lightweight), the chosen solution of our project is to substitute laminated structures by multidirectional ones based on 3D warp interlock fabrics. The best performances are supposed to be obtained with precise information on those structures from the very beginning of the manufacturing process. Their final geometry and mechanical performance have also to be verified with high precision. Therefore, local constraints on yarns during the weaving process have to be measured using in-situ measurements provided by fibrous sensor.

2. Method used

2.1. The needs

Sensors have to deliver live data such as yarn elongation, compression or friction. The more obvious way to collect such data is to use semi conductive materials that convert a change in geometry or volume, into a change of resistivity. So data can be recorded as an electrical signal. This technology has been used already in previous work at Gemtex by C. Cochran et al [1] and S. Nauman et al [2].

However to achieve in-situ measurements, sensors have to fill new requirements resulting of the special environment, and their motion. To measure mechanical forces applied on the yarn during the weaving process; basically the sensor need to be woven as a simple yarn and follow the same path. This path is defined by several devices of the weaving loom in which yarns have to go through on. The main weaving loom parts elements are described in figure 1:

- the take-up roller, just after the warp beam
- the heddles
- the reed
- the first weft yarn

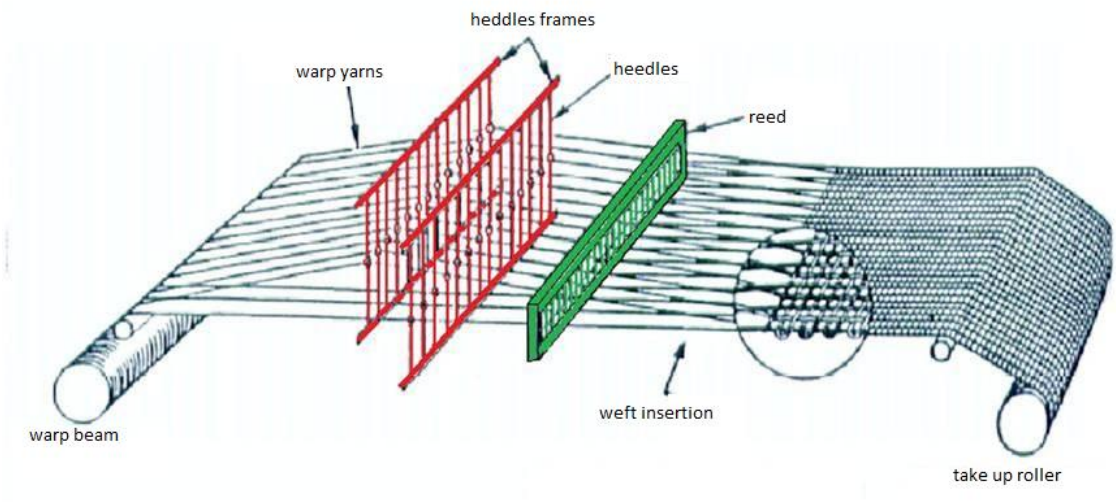

Figure 1: *Main weaving loom devices interacting with warp yarns*

2.2. Design of yarn sensor

The yarn sensor is assembled with several elements. Each element details are described in figures 2 and 3 below.

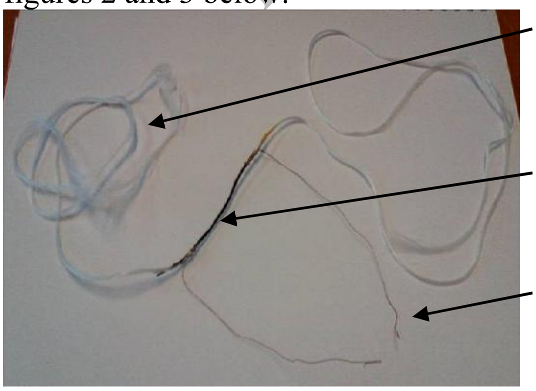

Figure 2: *Sensor yarn prototype*

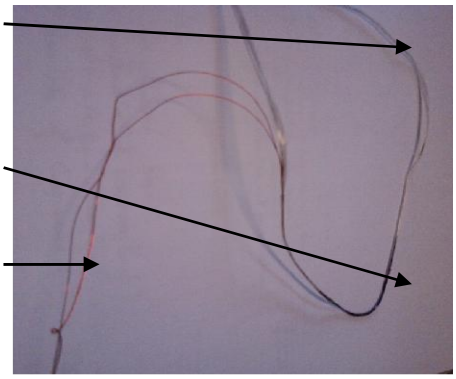

Figure 3: *close view of sensor yarn*

2.2.1. Core yarn

Two different options of core yarn have been achieved. The first type is to be coupled with an existing warp yarn and the second type is a structural yarn like those currently woven (glass fibre threads) and then replace a warp yarn by a sensor yarn. Both options have been tested and the second one appears to be the best. A better accuracy of measurements and an easier production process has been revealed for this sensor yarn type.

2.2.2. Sensitive coating

The sensitive coating used is based on a commercial conductive coating, Pedot/Pss ([10],[11],[12]). The Pedot is a conductive polymer, while the Pss can be dissolved into water. To complete this coating, carbon black particles have been added in order to improve conductive and increase percolation amplitude.

Some other coatings have been tested, such as carbon black/ Evoprene® (C.Cochrane [1]) or Carbon black/Epoxy. Both deliver good results for conductivity and sensitivity but seems to be difficult to implement and, then, restrict their repeatability.

2.2.3. Equipment

Sensors have to transmit the data to the recording device, still without interfering with the motion of the loom. For those purposes, copper wire are used to connect the sensitive coating to the recording device and a heat-shrink sleeve is fixed around the sensor to protect it and prevent it to snag on the yarn around and the loom elements. To prevent any risks of short-circuit, the copper wires are polyurethane isolated.

2.3. Recording devices

In addition to the yarn sensor, some devices must be used to record the signal from the sensor. The KUSB-3100 acquisition module is a simple way to connect the analogical sensors to a computer. It has already been used in previous similar researches (C. Cochrane [1], S. Nauman [2]) and proved good efficiency.

However this device alone reveals not sensible enough to detect the small change of conductivity of the sensor. Plugging the sensor in a Wheatstone bridge has been the solution to create a signal with greater amplitude variation. This system was already being used by S. Nauman [2] and has joined to an amplifier allowing gain and offset trimming (figure 4).

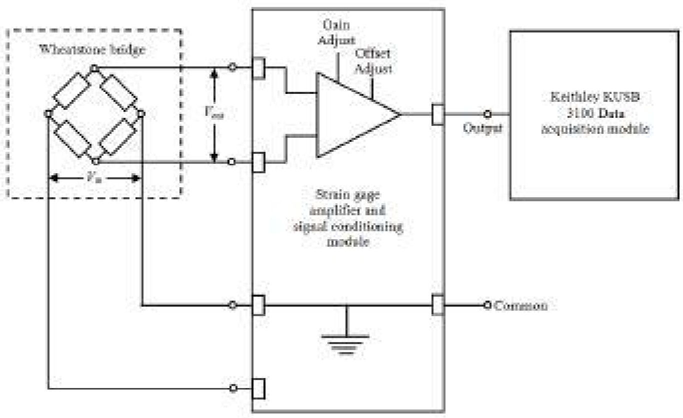

Figure 4: *Scematic of the recording devices*

2.4. Characterization of sensor yarn

Before their use, sensors are tested in order characterized them. The main parameters measured are the length of the sensitive coating and its resistivity. Then sensors are tested on a tensile strength MTS tester (figure 5). This test is performed to visualize the reaction of sensors during mechanical load cycles of charge and discharge. Then the data collected from sensors are compared to data provided by the tensile strength tester. The test procedure is design to provide similar stresses and elongation values than appearing during the weaving process.

Figure 5: T*ensile strength Mts tester*

3. Results

3.1. Percolation point

It is important to find the optimal percolation point (figure 6) for the coating in order to maximise the change in conductivity for a given elongation of the sensitive part. Several concentrations of carbon black, in a Pedot solution, have been tested with consecutive value. The resistivity of each of these coating has been measured and the curve of resistivity against concentration has been drawn.

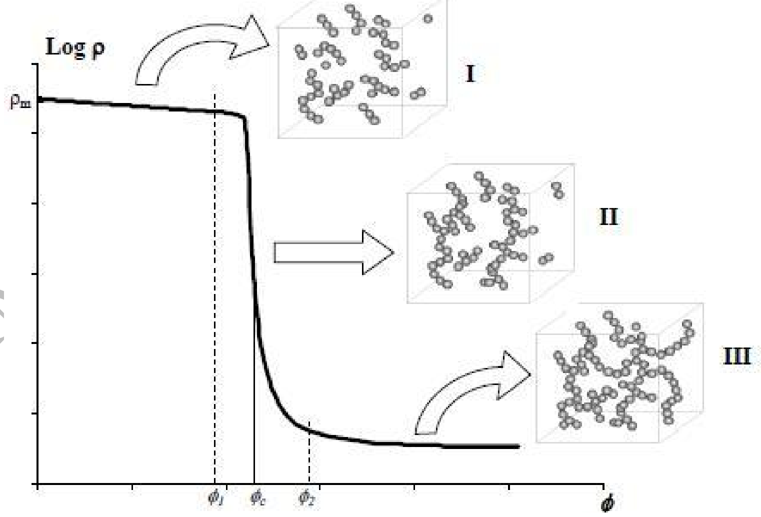

Figure 6: *resistivity against conductive particles concentration*

3.2. Physic characterization of the current sensors

Results show that applying the coating in two successive layers reduce both resistivity and the interval resistivity of sensors.

Currently the sensors in use offer resistivity between 0.4 and 1.4kOhm/cm (Coating length around 60mm). They are developed on 300 Tex E-glass roving and the length of the core yarn is long enough to fit in between the warp yarns and go through.

3.3. Results of characterization

Prior to be used for in situ measurements, sensors must be tested on a tensile strength machine for characterization. This last stage aim to establish the "strain/stress" and "strain/ ΔR/R" sensors graphs. Those graphs will then be used as reference to read and interpret the data collected during in situ measurements.

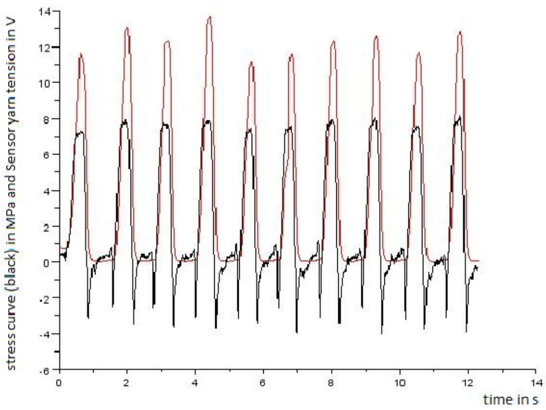

***Figure 7:** Strain and voltage versus time*

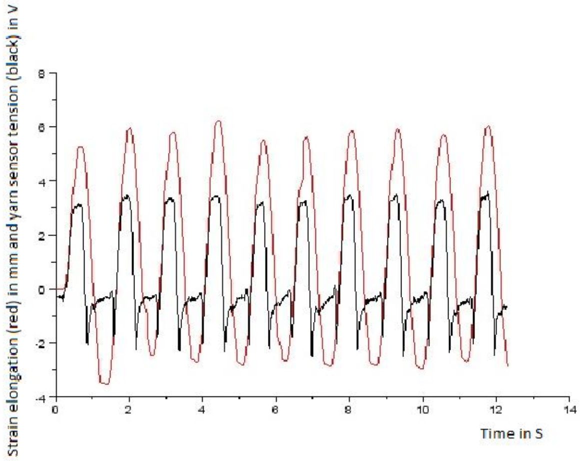

***Figure 8**: Elongation and voltage versus time*

The first task consists in linking the data of the tensile strength tester to the records of the sensor. The time basis being independent for the two devices, this task is very important for the rest of the analysis. In the end the number of figures must be equal from both sources. This first stage gives also the general behaviour of sensors to strain and elongation. Usually the load peaks look pretty similar but "unload" areas reveal quite imprecise (figures 7and 8).

Taking into these parameters, it's possible to draw the Strain/stress and Voltage/stress graphs (figure 9). The first one setting the mechanical behaviour of the sensor and the second providing the voltage in the sensor for a range of stress solicitations.

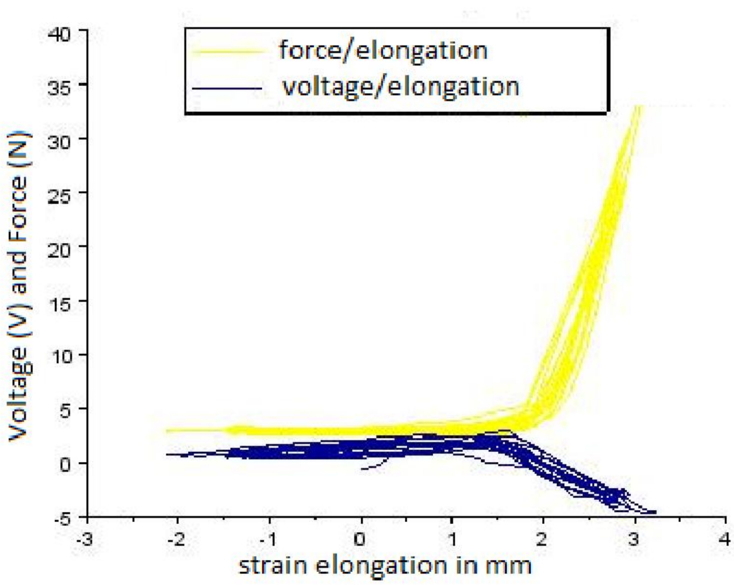

***Figure 9: comparison between force/elongation and** voltage/ elongation*

3.4. First in situ measurement

In early stages of development, sensors have shown great hopes for future in situ measurements. When a prototype of sensor has been implanted in a manual weaving loom, the results shown good sensitivity to yarn elongation (on heddles lift). Noise due to vibrations or electrical parasites did not disturb the measurement. And even compression was recordable by the sensor prototype.

However going from a prototype of sensor to a full size sensor, ready to use on a weaving loom, seems to be more complex. Many options were tested in order to achieve good efficiency and solve problems like connectivity of sensors or repeatability. In figure 10, it can be seen the evolution of the voltage in the sensor while passing the heddles spot. The first voltage peak reflects the start of the weaving loom. Then, the series of small oscillations represent the vibrations of the yarns being in the heddles zone. The biggest oscillations mean that the heddle, where the sensor yarn goes through, is lifted which create elongation of the sensor. The quite flat end of the recording shows the end of the heddle zone.

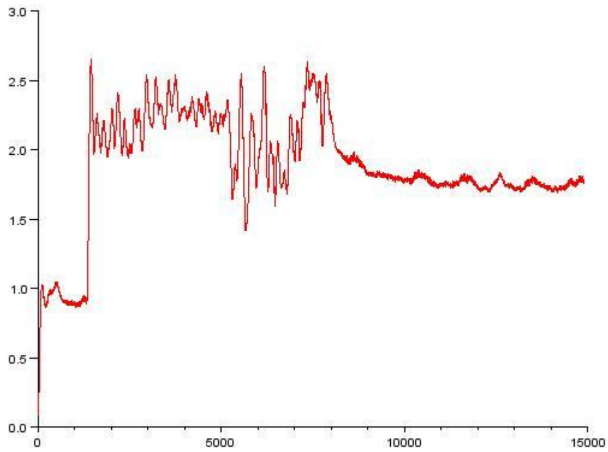

Figure 10: *In-situ measurement in voltage versus time*

4. Conclusion and Prospects

The dynamic in-situ measurements of 3D composite material mechanical constraints during the weaving process have never been done before; hence new process, technology and devices have to be developed to achieve these measurements. Thus, the design of new sensor yarn able to resist to dynamic stresses during the weaving process push to develop new coating method to ensure safe and homogenous distribution all around the yarn. Experimental results confirm the accuracy of this new sensitive coating during the mechanical stresses done on the sensor yarn by the different weaving loom devices. Future works will be to collect and treat data in order to find the equivalence with mechanical stresses.

Acknowledgements

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