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# Creep Detection in Composites with Silicon Strain Gauge

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**Summary:**

This work shows how the insertion of silicon mechanical sensors into composite structures enables the detection of internal structural variations, and can find applications in process monitoring or structural health monitoring. It includes the description of a novel process for minimally intrusive insertion of sensors inside composites (substrate free transfer printed sensor). Temperature and deformation characterizations reveal a modification of the internal structure of a composite, triggered by a sufficiently high temperature, and linked to the creep phenomenon of the composite's epoxy resin binder.

**Keywords:** Strain Gauges, Temperature sensors, Structural Health Monitoring, Microcrystalline silicon, Composites.

## Background, Motivation an Objective

Composite materials are increasingly used in a wide range of applications. The optimization of manufacturing parameters and the monitoring of their structural state are key issues in terms of safety, environment and production cost optimization [1]. Some solutions exist for introducing sensors into composites [2], but they remain complex to implement and intrusive. Our low-intrusive strain gauge instrumentation method provides physical and structural information at the heart of composites.

## Description of the Method

The process involves manufacturing microcrystalline silicon strain gauges and transferring them, without substrate, into one of the plies of the composite material. Characterization of these strain gauges as a function of temperature and deformation provides the physical features of the sensors. A structural change, initiated here by a coupling of deformation and increased temperature, is clearly identified by a sharp variation in the gauges' electrical resistance. This variation shows a degradation linked to a modification of the internal structure due to the creeping of the composite binder.

## Technology and results

The technology we've developed consists in fabricating the gauge on a temporary substrate [3]. Once the gauge has been fabricated, it is transferred to the composite ply made from a combination of fiberglass and epoxy resin. The sensor is then detached from its initial substrate. This functionalized ply is then inserted into a complete multi-ply composite structure. Metallic contacts and conductive wires are used for electrical characterization. The final structure is shown figure 1.

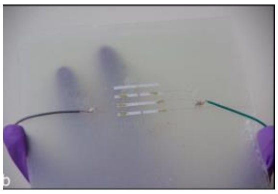

*Fig. 1. Composite with Silicon gauge.*

By characterizing the strain gauges in terms of temperature and strain, we can determine their features, such as their temperature coefficient and strain gauge factor. These factors are determined from the variation in the relative resistance of the gauges as a function of either temperature or the relative deformation of the structure. Those behaviours are shown in figures 2a and 2b.

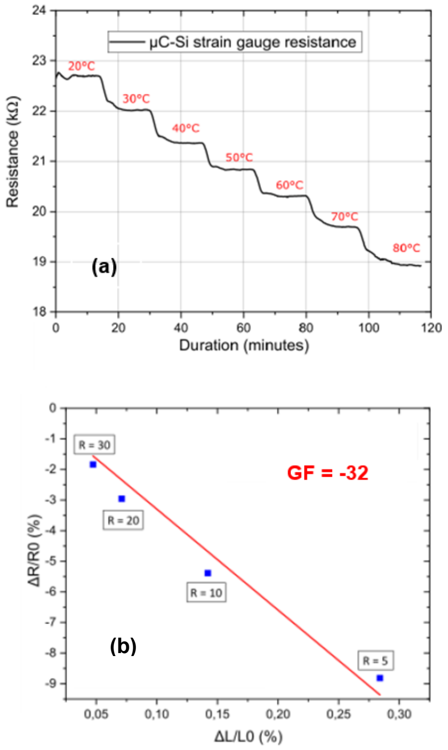

*Fig. 2. a. Resistance variation as a function of temperature, b: Gauge factor (GF) determination for microcrystalline silicon sensors inside composite.*

The relative resistance decreases with temperature, as usually for semiconducting material. From figure 2b, the gauge factor is determined from the slope of the relative variation of the resistance versus different curvature radius, linked to different relative deformations (ΔL/L). It is equals to -32, involving a sensitivity at the state of the art for microcrystalline silicon [4].

Figures 3a and 3b show the variation of the resistance with or without strain for increasing values of the temperature. When stress is applied, and the temperature exceed the value of 60°C, the gauges' electrical behaviour changes. This temperature causes the epoxy resin to creep and change its structure. This phenomenon is detected by an increase in the resistance value of the gauge. This increase, which becomes more pronounced at higher temperatures, corresponds to tension in the structure, involving micro-cracks and thus increasing the resistance value. The deformation of the composite remains visible as the structure cools.

As the internal structure of the silicon layer is altered by these microcracks, its resistance is higher than it was initially. However, the gauge still functioning. A loosening test of the structure (re-flattening by heating the composite) is also clearly identified by the relative variation in gauge resistance.

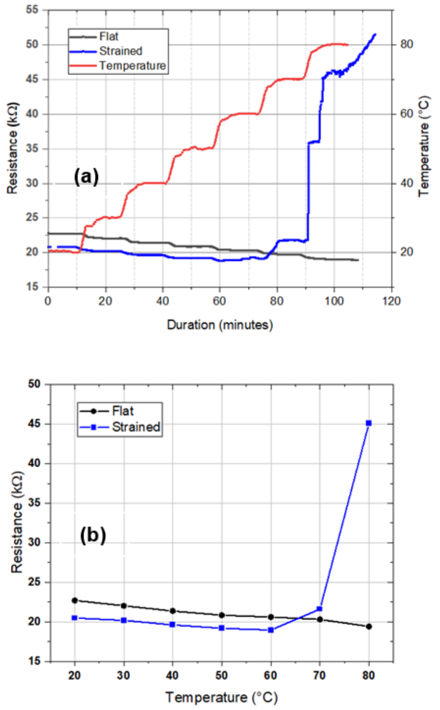

*Fig. 3. a. Resistance variation for flat and strained structure for different temperature steps, b: Variation of the resistance versus temperature, showing a change in the strained device above 60°C.*

## Conclusion

We have shown that it is possible to insert silicon strain gauges into the core of composite materials without damaging the device. These low-intrusive methods provide devices that can be used to measure both, internal temperatures or detect structural deformations. They also reveal major internal structural changes, such as binder creep and plastic deformation of composite materials.

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