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Low cost pressure sensors for impact detection in composite structures

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Abstract

A new technology of flexible pressure sensors is developed using conducting polymers as electroactive materials on plastic substrates. The sensor measures quantitative pressure and the use of an appropriate synthesis strategy in the electroactive material tuning an adequate electrical conductivity and film morphology allows working pressure ranges to be taylor-made designed. Using low cost materials, high surface sensors are easily fabricated. The present work describes the integration of this innovative, low cost and flexible technology on composite structures opening interesting potential opportunities for impact detection and measurements on these types of components.

Keywords: Flexible pressure sensors; Impact detection; Fiber composites

1. Introduction

Fiber composites have a widespread presence in modern industrial societies and, because of their special properties, they are continuously gaining importance. On one hand, our knowledge about the advantages of fiber composites and their properties is increasing and, on the other hand, since prices for aluminum and steel continue rising, there is also a substantial proliferation in the number of application of these materials in the fields of aerospace, automotive, civil engineering, or medical technology. For this reason, an accurate knowledge of the loading situation is just as significant for fiber composites as it is, in the sense of endurance strength, for conventional materials. Load monitoring is the first step for the calculation of structural health and lifetime under realistic conditions. A sensor technology specifically adapted to the properties of this material is becoming more and more important in order to be used for load analysis and component monitoring during operation. Relevant loads for the fatigue of composite can be best monitored with optical strain sensors. On the other hand, impact loads have also

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been monitored by piezoceramics sensors [1]. In this sense, some devices which are now in commercial state have already been developed, showing several variations in its configurations, being either capacitive or resistive pressure sensors. However, the currently developed configurations use metallic microparticles (silver) embedded on a polymer film, metallic central films (silver) separated by a pressurable elastomeric polymer film, or a combination of both of them, and consequently, these technologies have not an appropriate performance/cost ratio to monitore large surfaces [2]. In spite of the valuable advances, the use of high cost materials such as silver is a large inconvenient since large surface applications cannot be afforded by these type of sensors. In this work, a new technology of pressure sensors is studied for impact damage monitoring.

2. Methodology

2.1. Pressure sensor

The developed new technology uses two thin layers of conducting polymers as electroactive materials for the construction of pressure sensors. The conducting polymer films onto plastic substrates and the presence of a roughness at microscopic level lead to a resistivity decrease when different pressures are applied [3]. Poly(3,4-ethylenedioxythiophene) (PEDOT) aqueous dispersions were prepared by using an Ultrasonic Processor (model UP 400 S from Dr. Hielscher GmbH) during the synthesis. As an example, ethylenedioxythiophene (1 mL, 9.4 mmol) and 3.5 g of poly(styrene sulfonate, sodium salt) were dissolved in 100 mL of distilled water. To this mixture, an equimolar amount of ammonium peroxydisulphate (6.58 g, 28.8 mmol) dissolved in 50 mL of water was added dropwise over a period of 4 minutes. After 1 hour of reaction under ultrasonic irradiation, a dark blue PEDOT aqueous dispersion was obtained. Conducting flexible sheets were prepared by spin coating using a PET (polyethyleneterephtalate, 5×5 cm2 in surface, 125 μm in thickness) plastic sheet. 50 μL of conducting polymer ink were dispensed on it and it was rotated at 1500 rpm. A thin conducting film was created onto the plastic sheet, giving a conducting flexible plastic sheet. One of these conducting flexible sheets was screen printed with a dielectric material to obtain a non-conducting interface. A sensor device was thus constructed by superposing two of these layers (Fig 1a). When no pressure was applied on to the plastic sheets, there was no contact between conducting material. As the pressure on the plastic sheets increased, the contact between the microscopic irregularity at the conducting surfaces became higher and higher. Conducting rough surfaces progressively overlapped until a full contact was obtained at a specific pressure value. In fact, a calibration plot was obtained through applying pressure on to the sensor surface with different forces and recording the corresponding output voltage (Fig 1b).

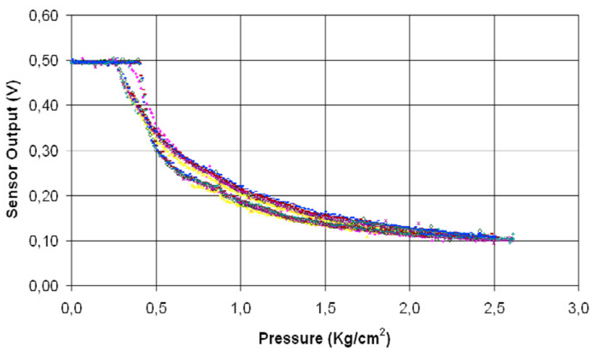

Fig. 1. (a) Flexible low cost pressure sensor based on conducting polymers; (b) the sensor's response

2.2. Smart composite structure

As a result of continuous progress in the fields of materials science, design methods and manufacturing technology, mechanical structures are already extensively optimized. This is especially true for high-performance lightweight structures in aeronautic engineering where transport aircraft structures are mainly manufactured by fiber composites. In our case, we previously built an ultralight structure formed by carbon fiber and rigid foam (Fig 2), specially used in aerospace applications. However, it is increasingly necessary to obtain smart structures capable of monitoring structural health. In this way, the special construction of fiber composite components, where individual layers are stacked one on top of the other, allows sensors to be embedded during production. Specifically, in our structure three sensors were embedded as follows: 4 carbon fiber layer, 1 flexible pressure sensor, 1 layer of 5mm rigid foam, 1 flexible pressure sensor, 1 layer of 5mm rigid foam, 1 flexible pressure sensor and 4 carbon fiber layer at the end. The rigid foam layers were drilled to allow the resin to penetrate to lower layers. The motivation for this integration often differs and is specific to the particular application. In this case, the aim of this work was to be able to detect impacts effects between different layers inside the composite structures.

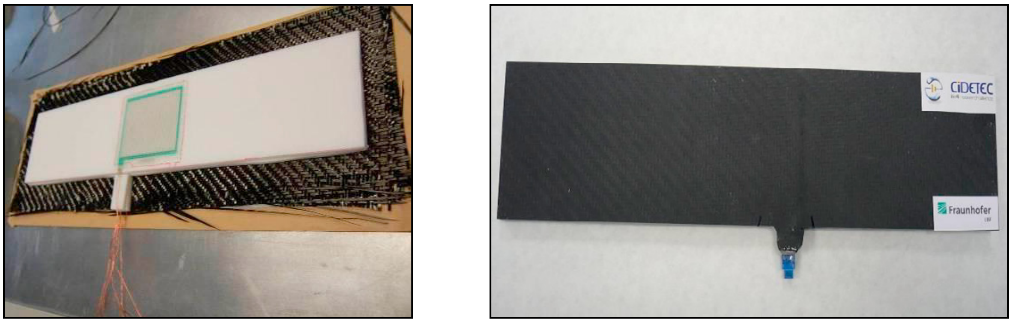

Fig. 2. Ultra-light structure with embedded flexible pressure sensors for impact detection

2.3. Impact tests

Impact tests were performed using a drop weight system. In particular, a Dynatup 9250HV test platform was used from the Fraunhofer LBF test laboratory, where aeronautic industry velocities (up to 20 m/s) can be generated.

3. Results and discussion

The manufactured smart composite structure was placed on the platform and different impact energies were applied. Then, both the applied force and the output voltage of three sensors (0-2 volts range) were measured. As shown in the Figure 3a, 0.5 Joules impact lead a force of 200N, enough to trigger at 55% the sensor located close to the surface (T). Meanwhile, the other sensors cannot detect any force. The second impact applied was 1 Joule (Fig 3b). In this case, the sensor above was saturated (100%) as a result of 500N force, and the sensor placed in the middle of the composite structure (M) started detecting the impact (35%). Nevertheless, the sensor located on the underside of the structure (B) did not measure any pressure. When the structure was subjected to an impact of 2 Joules (Fig 3c), sensor T had an identical performance: the force was high enough to saturate the sensor. However, the intensity of sensor M was higher (60% according to the full scale). Not even this force was enough to obtain any signal from sensor B. Finally, the figure 3d presents the result of applying 5 Joules energy impact. In this case the applied energy achieved the activation of sensor B (25%), placed furthest from the point of impact. Additionally, the delay that occurs in the transit of energy from the upper to lower layers was observed. In this kind of structures impact damage can involve extensive cracking throughout the laminate-thickness even if no damage is apparent in visual inspection of the component's surface. Therefore, the integration of this thin, flexible and plastic pressure sensor technology between the layers of the composite structure could be used as an efficient tool for the monitorization of the impacts and the analysis of the damage that has been occurred. At last, it is worth noting that this technology can be integrated to all type of surfaces as a low cost solution.

4. Conclusions

A new sensor technology is developed using conducting polymers. This technology shows great advantages for impact detection on high-surfaces due to: a) Plastic sheets being used final sensor devices are light; b) Sensors being low cost, it is thus a competitive technology to be incorporated on high surfaces. The integration of this thin, flexible and plastic pressure sensor technology between the layers of the composite structure allows the monitorization of the impacts and the analysis of the damage that has been occurred.

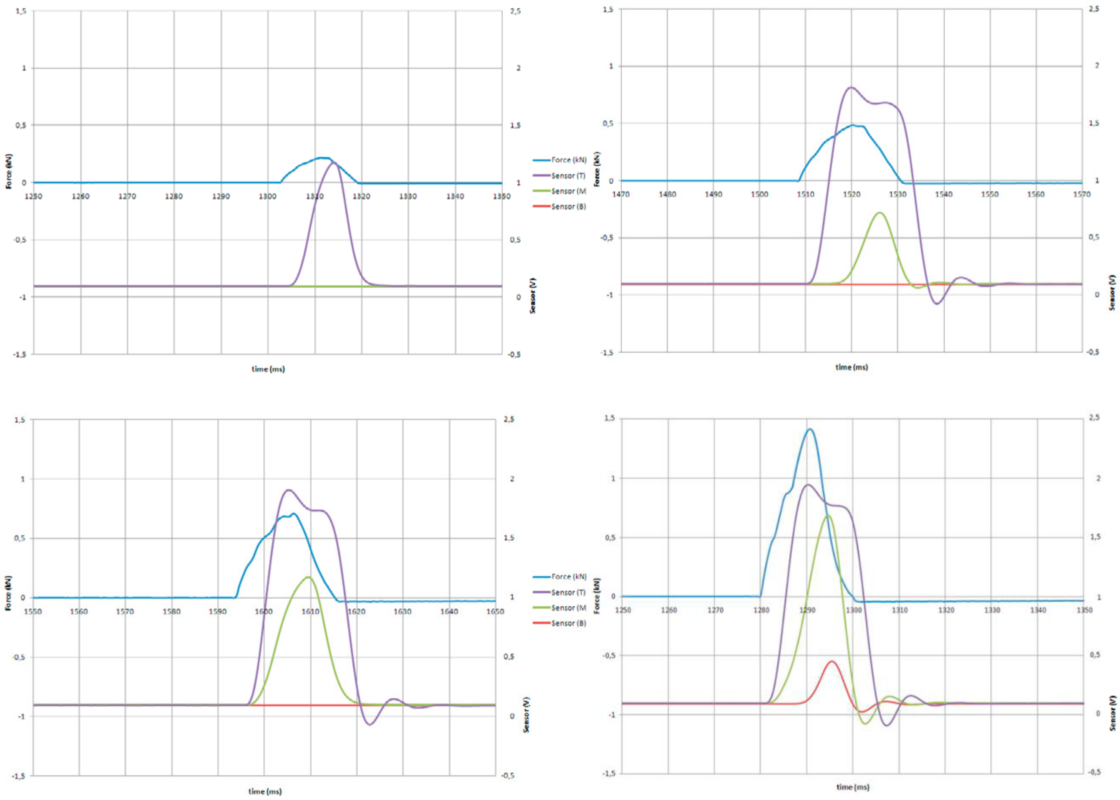

Fig. 3. (a) 0,5 Joule; (b) 1 Joule; (c) 2 Joule; (d) 5 Joule impacts measured by 3 pressure sensors integrated between composite structure layers.

Acknowledgements

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