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SENSING SKIN FOR IN-SERVICE MONITORING OF WOVEN COMPOSITE LAMINATES SUBJECTED TO IMPACT DAMAGE

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ABSTRACT

Damage of in-service composite structures is commonly caused by impact. In higher-energy impact events, the impact damage is clearly visible on the surface of the composite. However, this is not the case for low to medium energy impacts where extensive damage can manifest itself internally or on the back surface of the structure (e.g., blowout) with very little or no visible damage on the surface. This class of damage is called "barely-visible impact damage" (BVID). This work proposes and experimentally verifies a sensing skin for the detection, localization, and quantification of BVID in unidirectional and woven composite laminates. This highly scalable sensing skin is composed of a matrix of flexible large-area capacitive sensors that transduces a change in geometry of the composite (i.e. damage) into a measurable change in capacitance and is designed for the long-term health monitoring of in-service composite structures. In this work, an experimental testing campaign is undertaken to investigate the sensitivity of the sensing skin for the detection of BVID in carbon fiber-reinforced composites. Verification is performed using Quantitative Ultrasonic Image Correlation (QUIC) and results demonstrate that the sensing skin is capable of detecting, localizing, and quantifying damage once a minimum damage size is achieved.

Keywords: electromagnetism, history, science

NOMENCLATURE

SEC	soft elastomeric capacitor
BVID	*barely-visible impact damage*
CFRP	carbon fiber reinforced polymer

1. INTRODUCTION

Damage to in-service carbon fiber reinforced polymer (CFRP) parts is commonly caused by low-energy impacts. In the case of aerospace components, these impacts may be from the dropping of objects during inspections, maintenance, or operation. While higher-energy damage is clearly visible on the surface of the composite, damage caused by low and medium-energy impacts may not be visible to the naked eye [1,2]. However, these low and medium impacts can cause extensive internal damage. In-service damage is most often caused by impacts. In CFRP composites, impact damage results in matrix cracking, delaminations of the ply layers, and blowout on the back side of the composite. In some cases, little to no damage can be seen on the surface on the composite structure despite the internal damage being extensive, such damage is termed barely-visible impact damage (BVID).

This work proposes and experimentally verifies a sensing skin for the detection, localization, and quantification of BVID in unidirectional and woven composite laminates. This sensing skin is made-up-of large-area capacitive sensors termed soft elastomeric capacitors (SEC). The SEC is a robust and durable sensor that is customizable in both shape and size. One particularly useful attribute of the SEC is its capability to measure the additive strain of a structure ($\varepsilon x + \varepsilon y$). If uni-directional strain maps are necessitated for an application, a network of SEC sensors can be deployed and the additive strain decomposed into its constituent parts [3]. In previous work, the SEC has been characterized for both its static [4] and dynamic [5] behaviors. Additionally, the SEC has been investigated for specific applications including detection of fatigue cracks in steel bridges [6], monitoring of large cracks in concrete [7], and the detection and localization of damage on a wind turbine blade [8]. This study represents the first investigation of SECs for the monitoring of impact damage.

2. MATERIALS AND METHODS

2.1 Soft elastomeric capacitor

The SEC, shown in figure 1, is a parallel plate capacitor and as such is composed of three layers. The two electrically conductive electrodes are separated by a dielectric layer as illustrated in figure 1(b). The SEC benefits from a simple and low-cost fabrication process. First, SEBS is dissolved using toluene, after which TiO2 is dispersed using an ultrasonic tip. The solution is drop-casted to create the dielectric and the toluene let evaporate. Next, a carbon black conductive paint is applied to either side of the dielectric to create the electrodes of the parallel plate capacitor. Copper contacts with conductive adhesives are added to each electrode. A more detailed description regarding the fabrication processes of the SEC sensors can be found in reference [5].

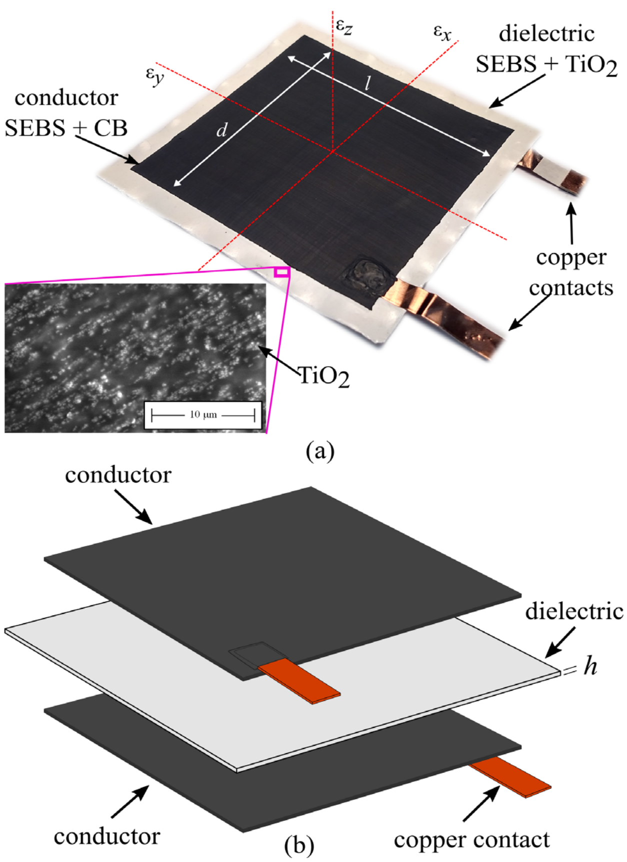

Figure 1: Figure 1: The soft elastomeric capacitor (SEC): (a) picture of a sensor used in this study with key components annotated with the inset showing a scanning electron microscope image of the dielectric; (b) an exploded view of the sensor geometry with key components annotated.

2.2 Damage detection mechanism

For the preliminary investigation presented in this work the damage detection mechanism is presented in figure 2 where an impact damage on the surface of the material results in a damage through the body of the CFRP material. This damage manifests itself as a blowout on the back side of the CFRP composite. For the assumed damage case, the SEC on the back side of the composite is deformed. This change in deformation results in a change in the geometry of the SEC mounted on the back of the composite specimen.

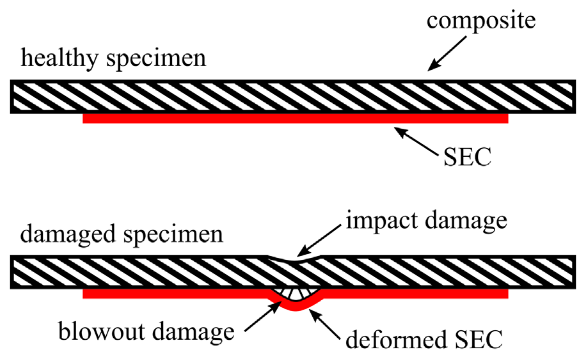

Figure 2: Proposed method for monitoring of barely visible impact damage using a soft elastomeric capacitor (SEC) mounted on the opposite side of the impact.

2.3 Impact testing

Impact testing was performed using 2 CFRP samples. Each sample measured 90 x 2000 x 3mm with a 75 x 75 mm SEC attached to the surface of the CFRP composite using an off-the-shelf two-part epoxy (JB-Weld). The test specimen is shown in figure 3. The drop tower setup used for impact testing is presented in figure 4. An LCR meter (B&K Precision 880) was used along with a laptop to collect data during the test. A series of 4 30 J drop tests were performed on the single specimen.

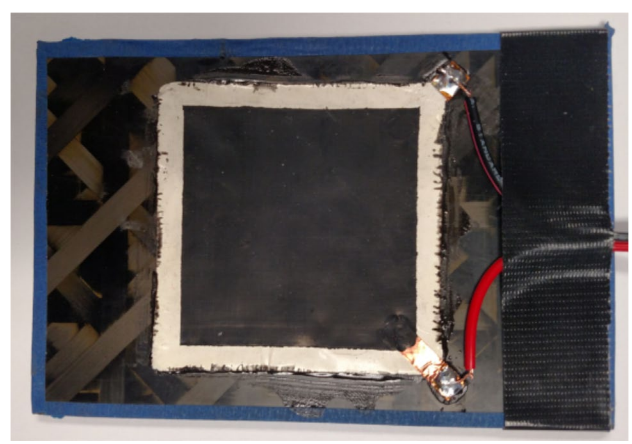

Figure 3: SEC sensor attached to the CFRP composite for impact testing.

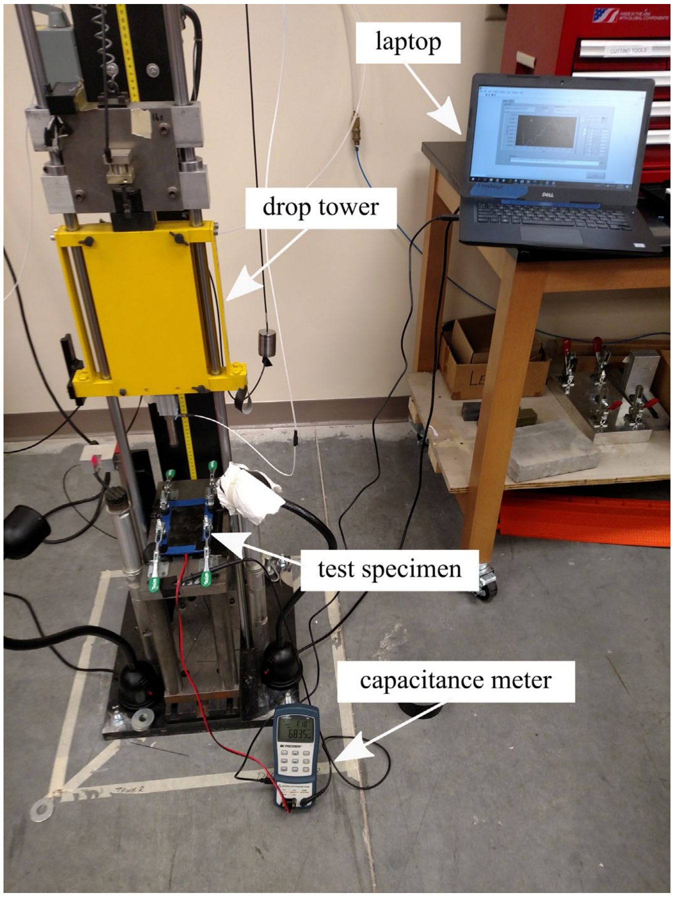

Figure 4: Impact testing setup used in this work.

3. RESULTS AND DISCUSSION

Results are reported in figure 5 for the 4 successive 30J impacts. Each impact resulted in an increase in the measured capacitance of the SEC sensor. This increase in capacitance is to be expected as the blowout on the back of the CFRP

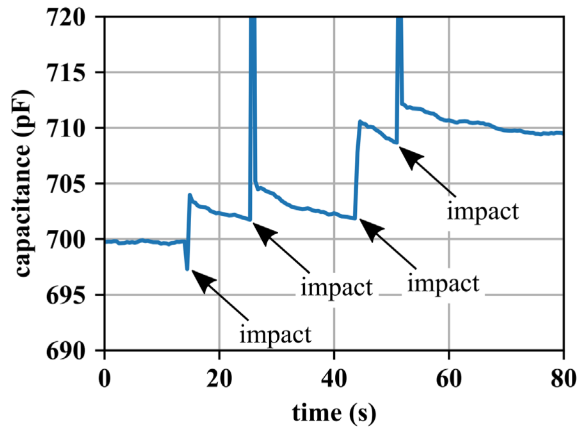

Figure 5: Figure : Capacitance results for four successive 30J impacts with each impact annotated.

composite results in an increase in the area of the SEC sensor as annotated in figure 2. Following the impacts, the capacitance converges onto a new baseline that accounts for the changed geometry of the composite in the plate.

4. CONCLUSION

This paper presented an experimental investigation into the use of soft elastomeric capacitors (SEC) for impact detection. It was shown that the SECs are capable of detecting impact in composites specimens through monitoring the blowout on the back of the sensors. Future work will verify the impact damage using Quantitative Ultrasonic Image Correlation (QUIC). Furthermore, the use of QUIC will be used for the quantification of the minimum detectable damage size.

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