Hybrid Carbon Fiber Composite for Non-Contact Stress Sensing via Piezospectroscopy

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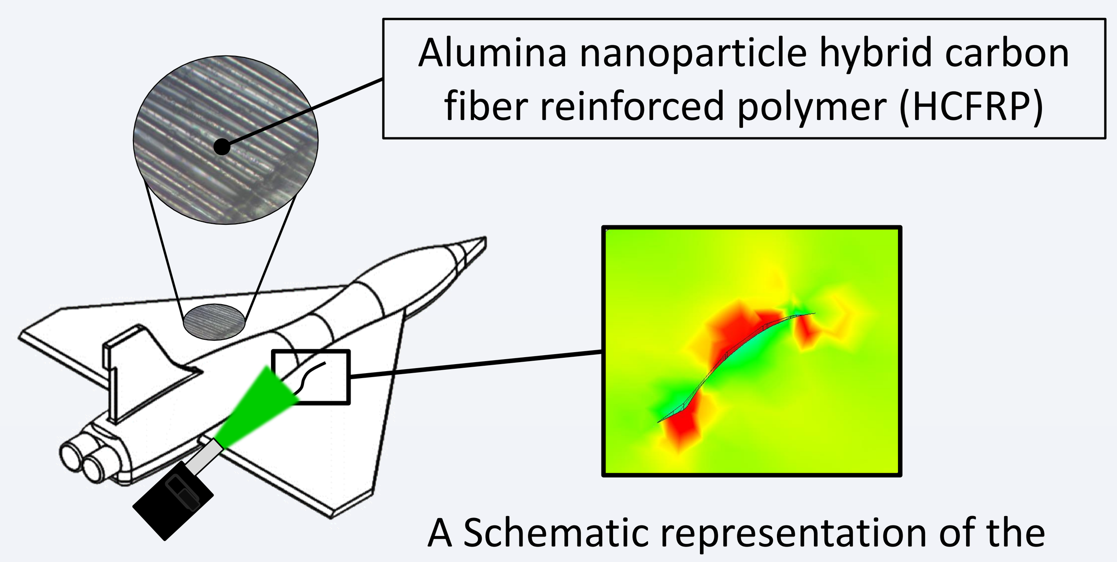
ADVANCED STRESS SENSING

An aerospace structure manufactured using a certain hybrid carbon fiber composite with embedded nano stress-sensors can reinforce the material and introduce inherent advanced stress-sensing capabilities.



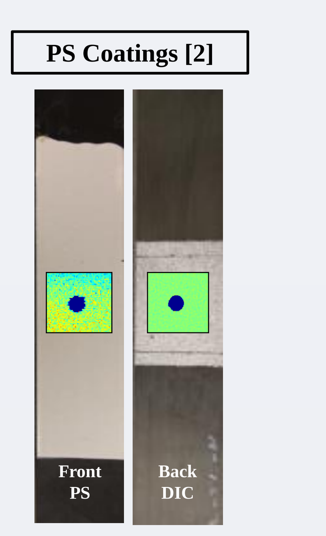
A Schematic representation of the stress map result for future application

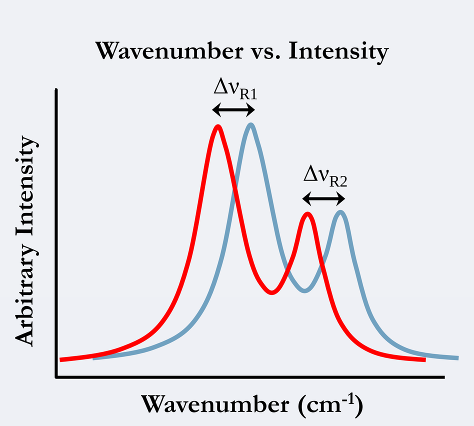
OBJECTIVES

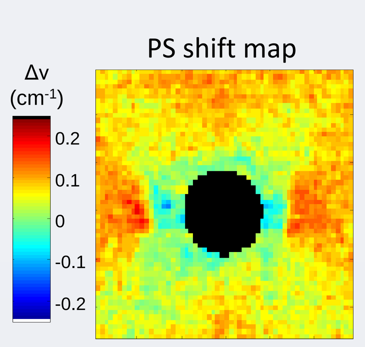
- Experimentally measure stress-sensing capability introduced in a carbon fiber composite with embedded alumina nanoparticles through piezospectroscopy
- Characterize particulate dispersion through photo-luminescent mapping.

PIEZOSPECTROSCOPIC COATINGS

Piezospectroscopy (PS) is a laser based stress sensing technique, which involves monitoring the spectral emissions of photo-luminescent materials as they change with stress. Through the piezospectroscopic effect, previous work utilized aluminum oxide (alumina) epoxy nanocomposites as stress sensing materials [1].



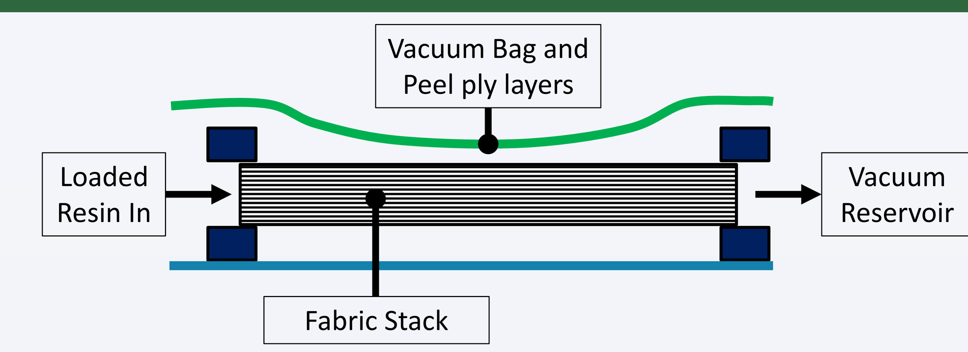




Specifically, piezospectroscopic (PS) coatings have been successfully used for non-contact stress sensing and early damage detection [2,3]. The success of PS coatings led to the implementation of stress-sensing in this hybrid composite study. Some benefits of the hybrid composites approach include enhanced manufacturing and improved mechanical properties.

HYBRID COMPOSITES & STRESS MAPPING METHODS

The composites used in this work include unidirectional carbon fiber and an epoxy matrix loaded with alumina nanoparticles. This composite, which includes both a fibrous filler as well as a particulate filler, is commonly referred to as a hybrid carbon fiber reinforced polymer (HCFRP). The alumina HCFRP was manufactured at Imperial College London using a resin infusion under flexible tooling (RIFT) technique [4].

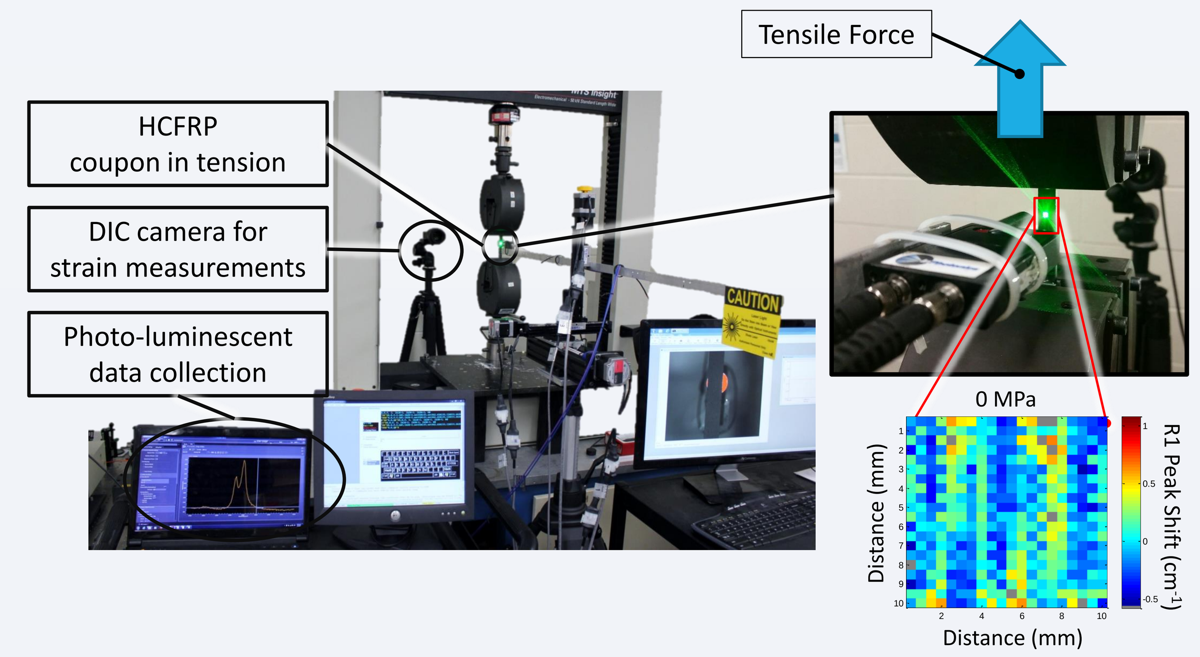


In order to determine the HCRFP's stress sensing capabilities, the samples were loaded in tension using a mechanical testing system. Therefore, Aluminum end tabs were adhered to the ends of the samples through a quick setting epoxy; this allows for the course-textured testing grips to latch onto the sample without damaging it.

Final sample with end tabs

The Final samples are of dimensions 10 mm by 100 mm by 3 mm, fitted with aluminum end tabs. There were four varying HCFRP, each with a different amount of alumina nanoparticles: 5, 10, 15, and 20 weight percent alumina. In the manufacturing of the 10 weight percent alumina, difficulty in achieving comparatively uniform dispersion was experienced.

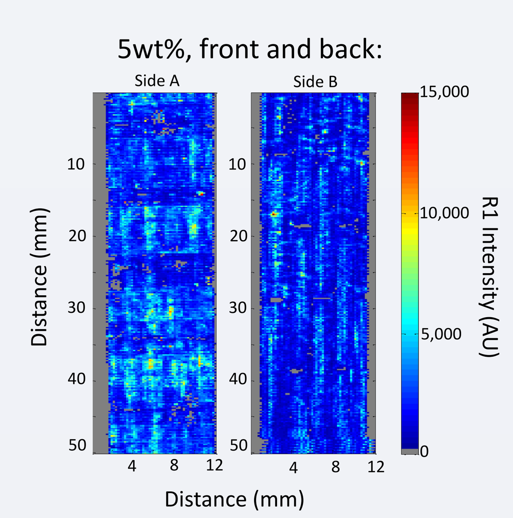
Parameter	Value
Max Hold	450 MPa (≈25% UTS)
Number of Static Holds	18
Static Hold Intervals	750 N (25 MPa)
Spectral Map Dimensions	1 x 1 cm
Spectral Map (X by Y)	20 X 20 (500µm resolution)
Time per map (during hold interval)	3 min each



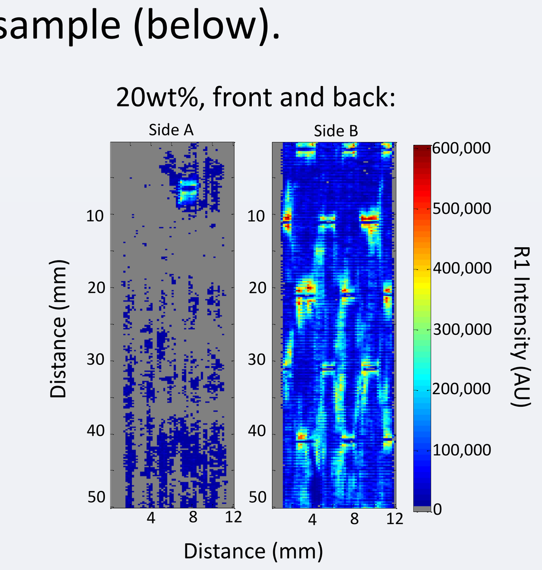
The Portable Piezospectroscopy System [5] was used to conduct the photoluminescence piezospectroscopic maps of the HCFRP's surface.

STRESS SENSING RESULTS

Particulate Dispersion

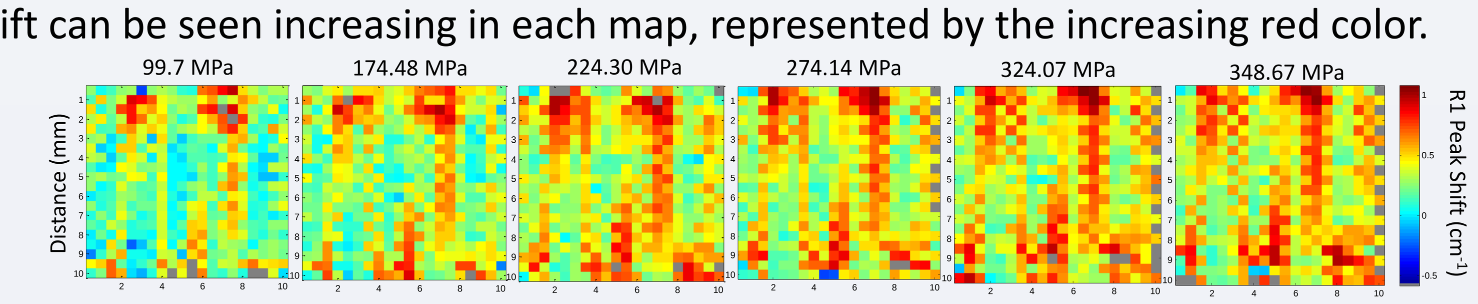


It can be seen the in the 5wt% sample (above), the particles are well dispersed. On the other hand, particulate sedimentation can be observed in the 20wt% sample (below).

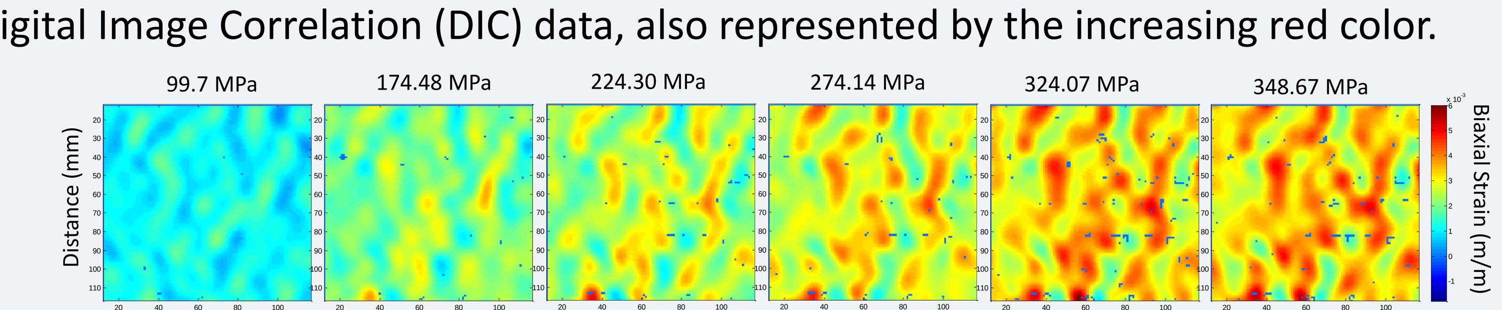


Non-Contact Stress Mapping

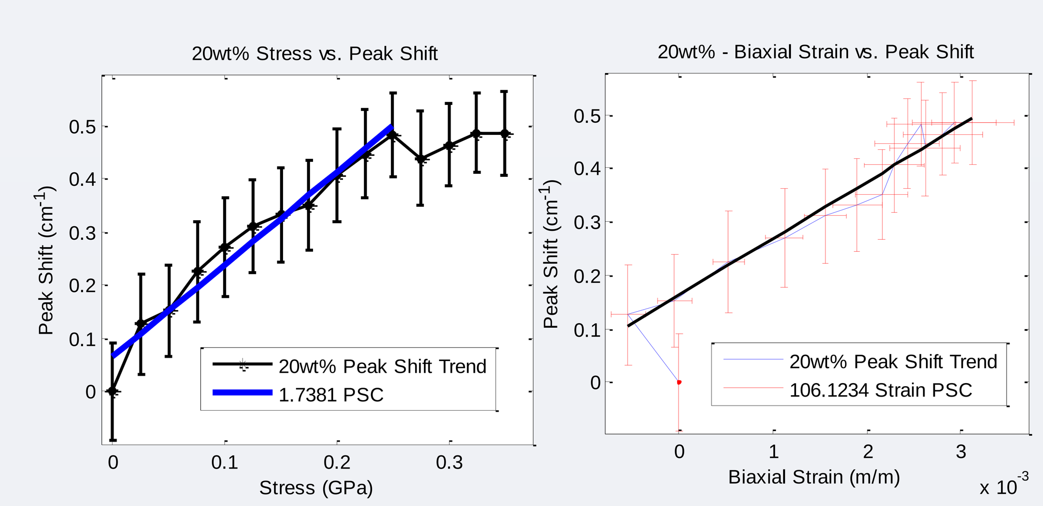
In the 20wt% Static Hold Piezospectroscopic maps, an overall positive (or tensile) peak shift can be seen increasing in each map, represented by the increasing red color.



A similar tensile biaxial strain trend can be seen increasing in the 20 wt% Simultaneous Digital Image Correlation (DIC) data, also represented by the increasing red color.

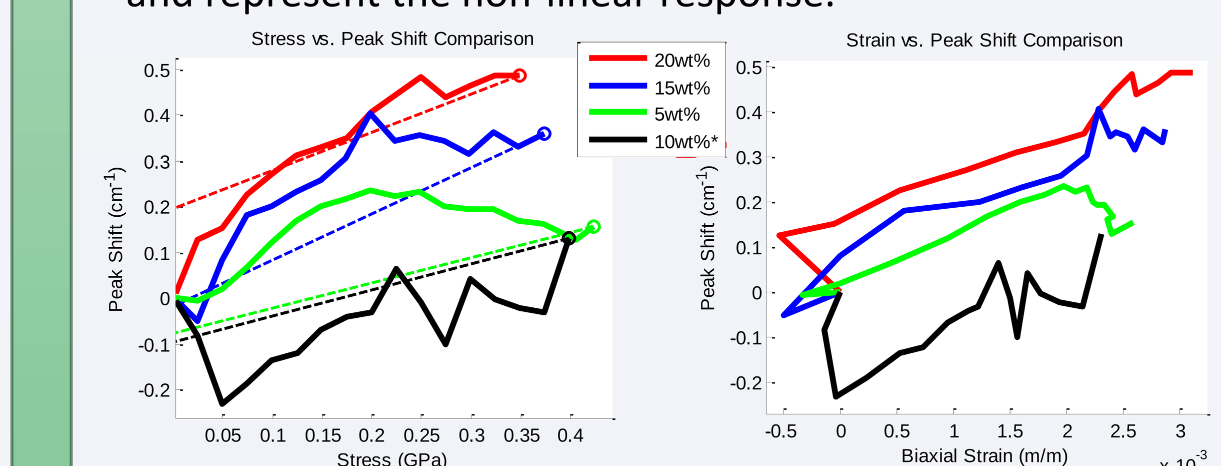


The average peak shift of each map at its respective stress and strain are plotted to the right, and a linear ramp-up behavior can be observed in both, the slope of which quantifies the PS coefficient (stress sensitivity). The PS error bars are representative of the non-uniformity of the surface, and the DIC strain data also reflects this surface non-uniformity.



DISCUSSION

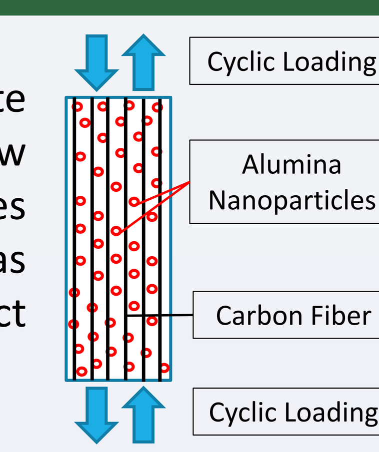
This study showed that the piezospectroscopic effect provides sensing capabilities in a hybrid composite that includes unidirectional carbon fiber and alumina nanoparticles. In general, with increasing alumina content, a more significant peak shift was observed (with exception of the 10wt%) indicating increased sensitivity to stress. However, methods outside of a linear slope representing the PS coefficient must be explored to adequately capture and represent the non-linear response.



Digital image correlation was conducted simultaneously, and complimented the non-contact piezospectroscopic sensing. Strain data showed similar trends to those observed with photo-luminescent mapping. It also appears that if the particles do not reach the de-bond point, they unload to a positive peak shift. On the other hand, if they de-bond, they unload to a negative peak shift.

FUTURE WORK

One area of future work is the complete mechanical characterization of this new hybrid composite, including composites with lower alumina contents, as well as the development of non-contact sensing of fatigue and creep behavior.



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