Spectroscopy on Composite Materials

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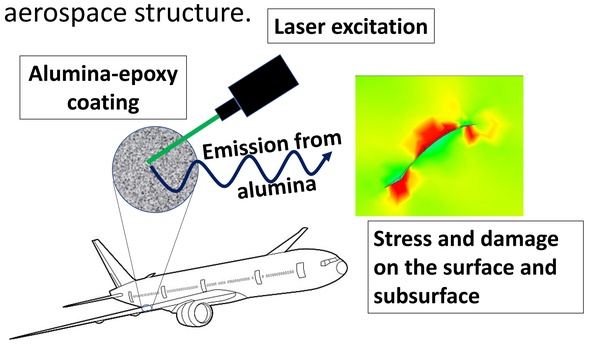
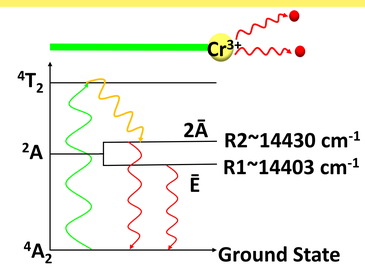
Motivation

The future of aerospace structures is highly dependent on the advancement of reliable and high performance materials. The application of stress sensing coatings on structural materials will allow for health-monitoring and the detection of damage before failure occurs. Using photoluminescent alumina nanoparticle as a coating material allows stress and damage sensibility through its piezospectroscopic characteristic. Calibration of this characteristic for coating on a metal substrate can be readily used for sensing stress and determining damage on aerospace structure.

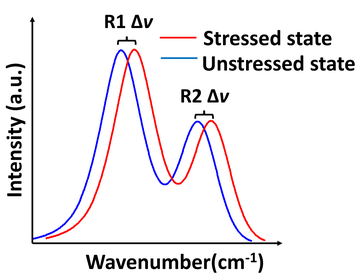


Schematic of photoluminescence coating for stress sensing

Piezospectroscopy (PS)



$$\Delta\nu = \pi_{ij}\sigma_{ij}$$



Excitation of chromium ion substitutional impurities results in emission of photons. The equation to the left represents the change in wavenumber to the stress tensor. Emissions comprised of R1 and R2 peaks which create the R-line doublet.

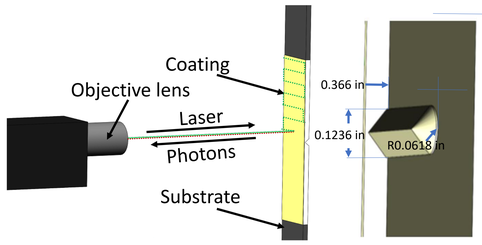
Experiment Procedure

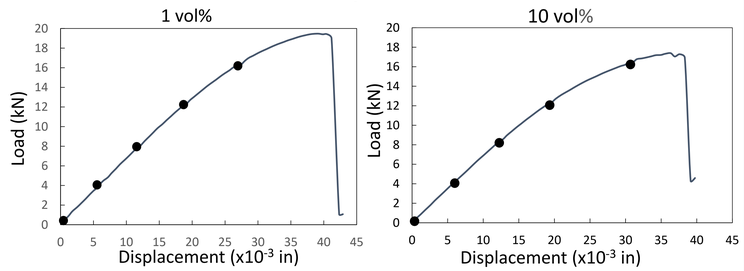
Front Back

- Notched aluminum tensile specimens made of 2024 Al of dimensions of 8.0 x 0.8 x 0.19 inches were used. Specimens were loaded using mechanical load frame to maximum load of 20 kN at increments of 4 kN or until the coating failed.

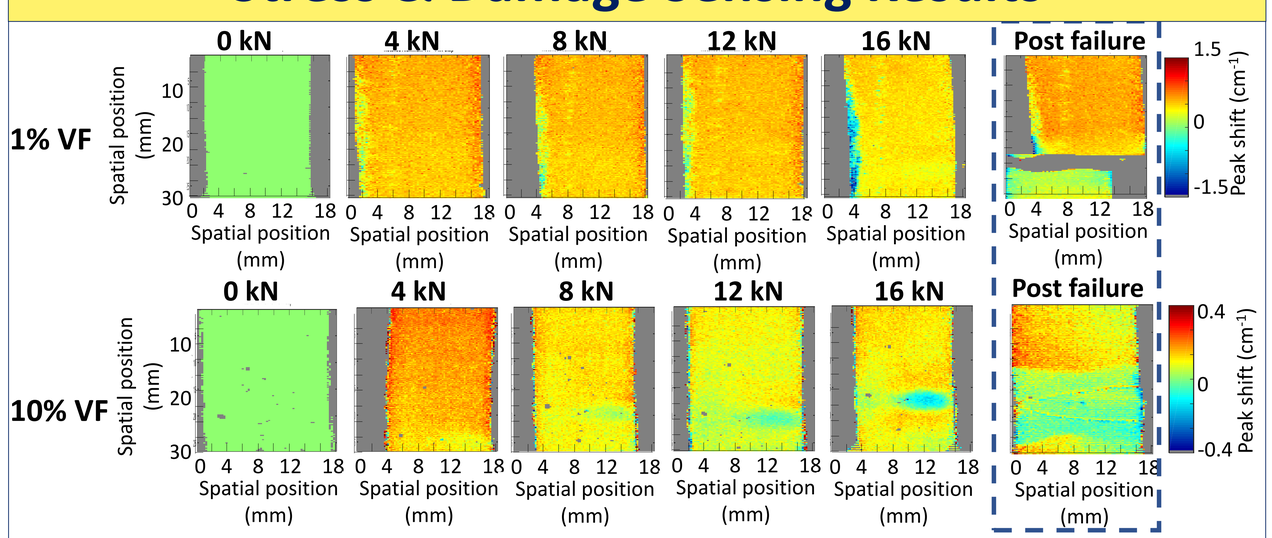
Volume fraction	Laser power	Exposure time	Resolution	Map size (X)	Map size (Y)
1%	30.1 mW	100 ms	200 µm	18 mm	30 mm
10%	10.6 mW	20 ms	200 µm	`18 mm	30 mm

- Two stress sensing piezospectroscopic coatings were used that consisted of Bisphenol A Epoxy, Epikure 3055, containing 1 vol% and 10 vol% alumina with a particle size of 150 nm.





Stress & Damage Sensing Results



- The peak position of both 1 vol% and 10 vol% is 14,402 cm^{-1} at zero load
- The figures show peak shift maps obtained from the piezospectroscopic measurements during tensile tests.
- The peak shift maps of both the coatings show signs of gradually increasing tensile stress.
- The peak shift map from 10 vol% coating can better capture the stress concentration associated with the notch.
- The peak shift map of 10 vol% coating captures the stress concentration due to subsurface notch at the load of 12 kN.
- The concentration in peak shift map indicates the site of subsurface damage initiation.
- The concentration in peak shift map can also provide the size of subsurface damage.

Conclusion

- Alumina-epoxy coating on aluminum is capable of determining full field stress including on subsurface stress concentration.
- Higher volume fraction of alumina nanoparticles showed higher stress-sensitivity of the coating.
- The piezospectroscopic coating can provide high spatial resolution image of stress field and the damaged area.

Future Work

- The peak shifts from piezospectroscopic measurements using alumina nanoparticles will be calibrated for quantitative measurement of stress in the specimen.
- Different volume fractions and particle sizes of nanoparticles will be studied.
- Other means of measurement will be used to validate the stress sensing capability of the applied coating.

References & Acknowledgement

[1] Hanhan, I., Durnberg, E., Freihofer, G., Akin, P., & Raghavan, S. (2014). Portable Piezospectroscopy system: non-contact in-situ stress sensing through high resolution photo-luminescent mapping. *Journal of Instrumentation*, *9*(11), P11005.

[2] Freihofer, G., Dustin, J., Tat, H., Schülzgen, A., & Raghavan, S. (2015). Stress and structural damage sensing piezospectroscopic coatings validated with digital image correlation. *Aip Advances*, *5*(3), 037139.

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