Stress Sensing of Alumina-Epoxy Coatings with Varying Volume Fractions of Alumina Nanoparticles using Photoluminescence Piezospectroscopy

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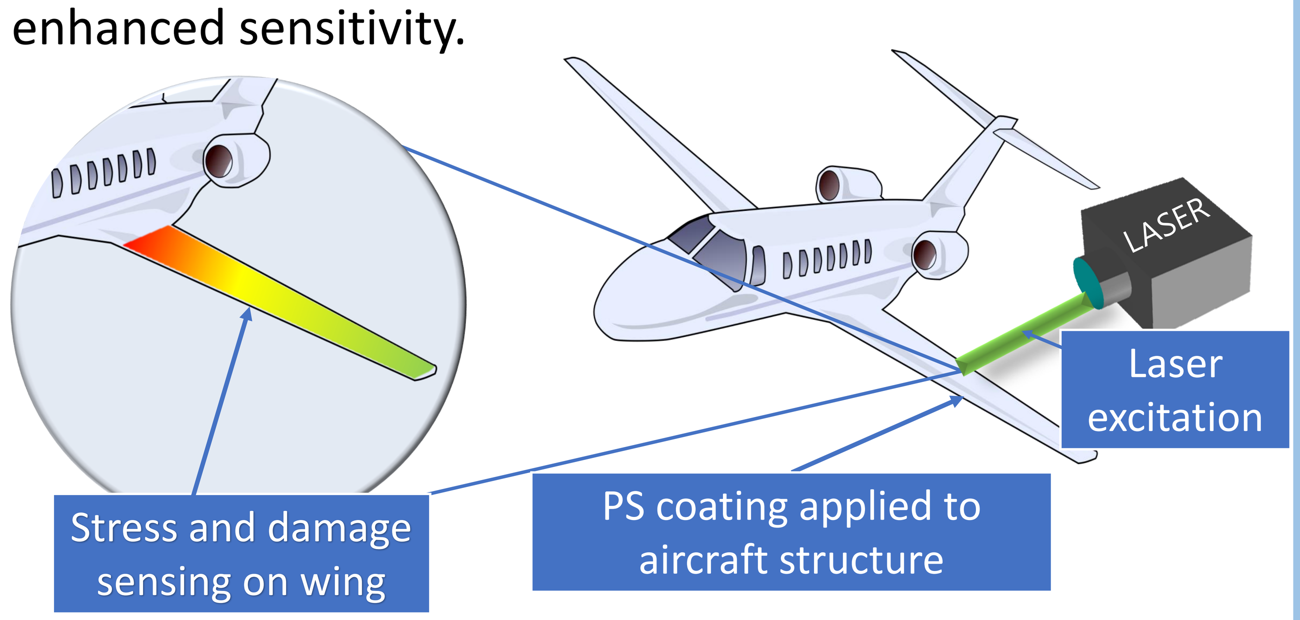
Motivation

Nondestructive evaluation (NDE) is used for maintenance checks in the aerospace industry. Stress sensing coatings can be applied onto aerospace structures for stress sensing and damage detection prior to failure. These coatings consist of α-alumina nanoparticles, which have photo-luminescent and piezospectroscopic (PS) properties that make stress sensing and damage detection possible. Defining the optimal parameters for an ideal working stress sensing (or PS) coating configuration is needed for enhanced sensitivity.



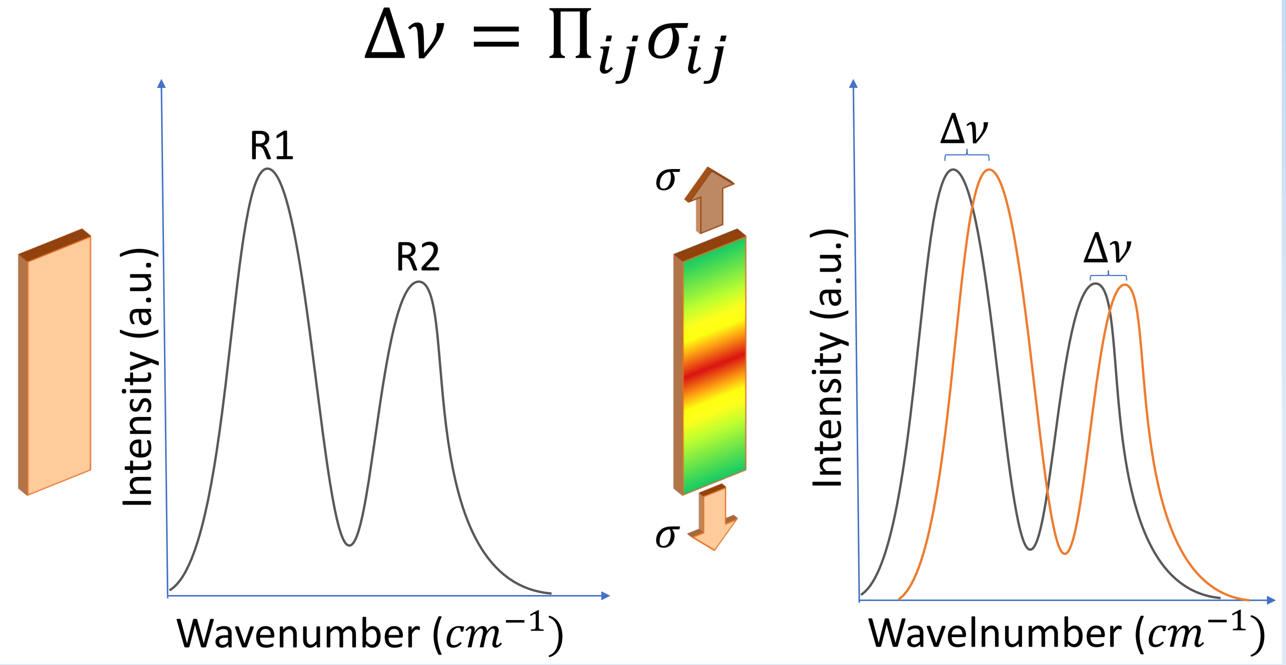
Objective

This study assesses the effect of α-alumina nanoparticle volume fraction on the piezospectroscopic (PS) coating's sensitivity to changes in stress.

Photoluminescence Piezospectroscopy

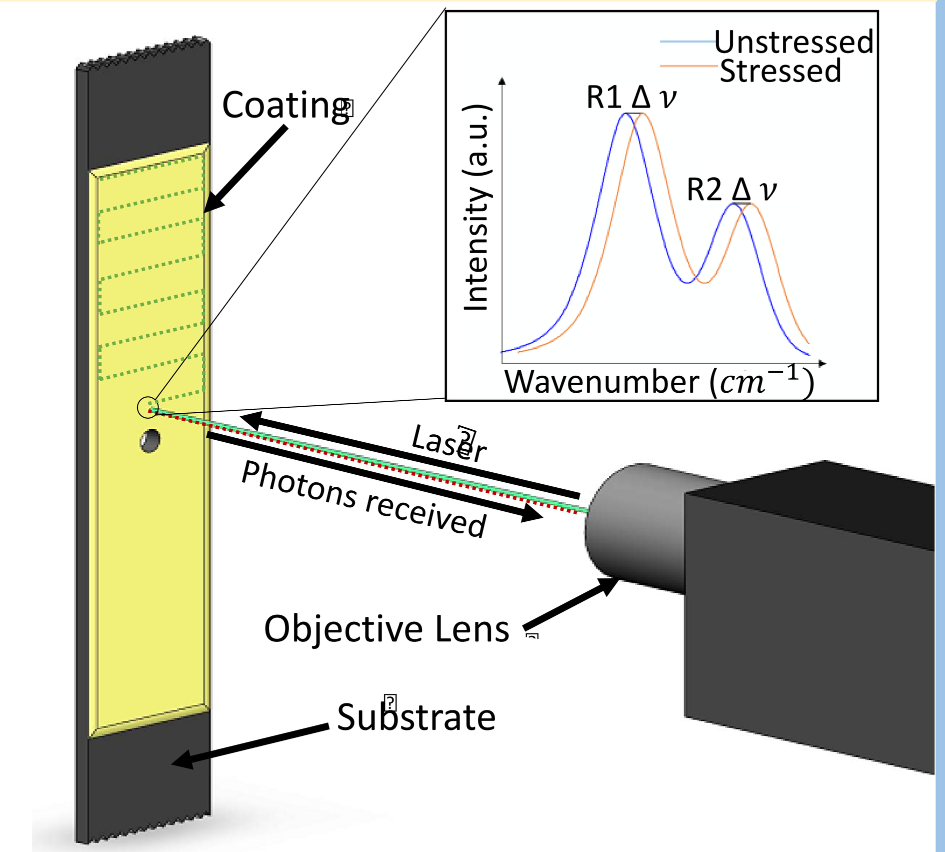
- Photoluminescence piezospectroscopy (PLPS) measures spectral peak shifts due to applied stress on α-alumina, a photo-luminescent material.
- When the chromium ion impurities in α-alumina are excited by a laser source, the resulting emissions produce R-lines with R1 and R2 peaks.
- The R-lines shift when a load is applied to α-alumina. This shift can be correlated with the following stress tensor equation.

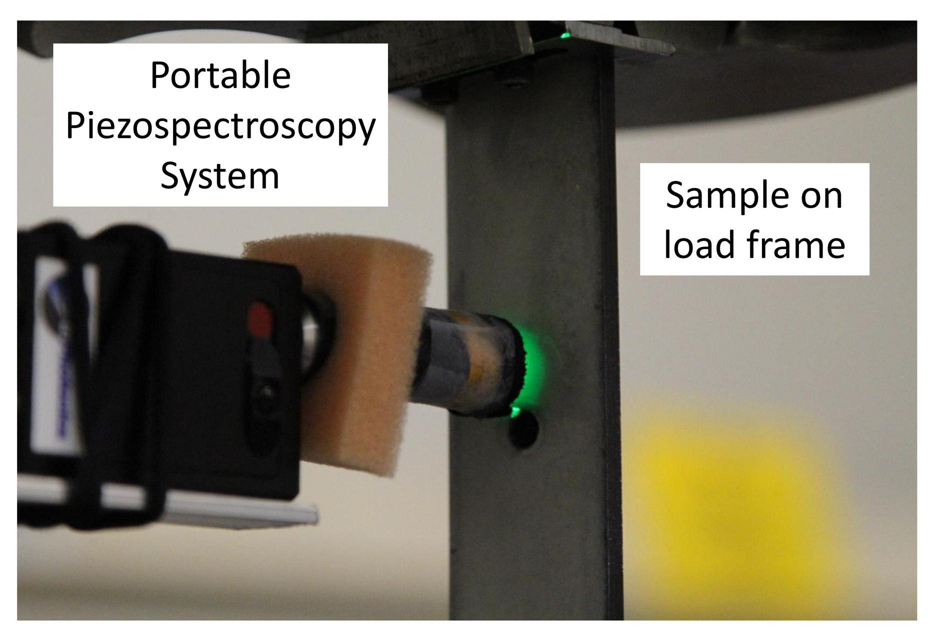
$$\Delta\nu = \Pi_{ij}\sigma_{ij}$$



Experiment Procedure

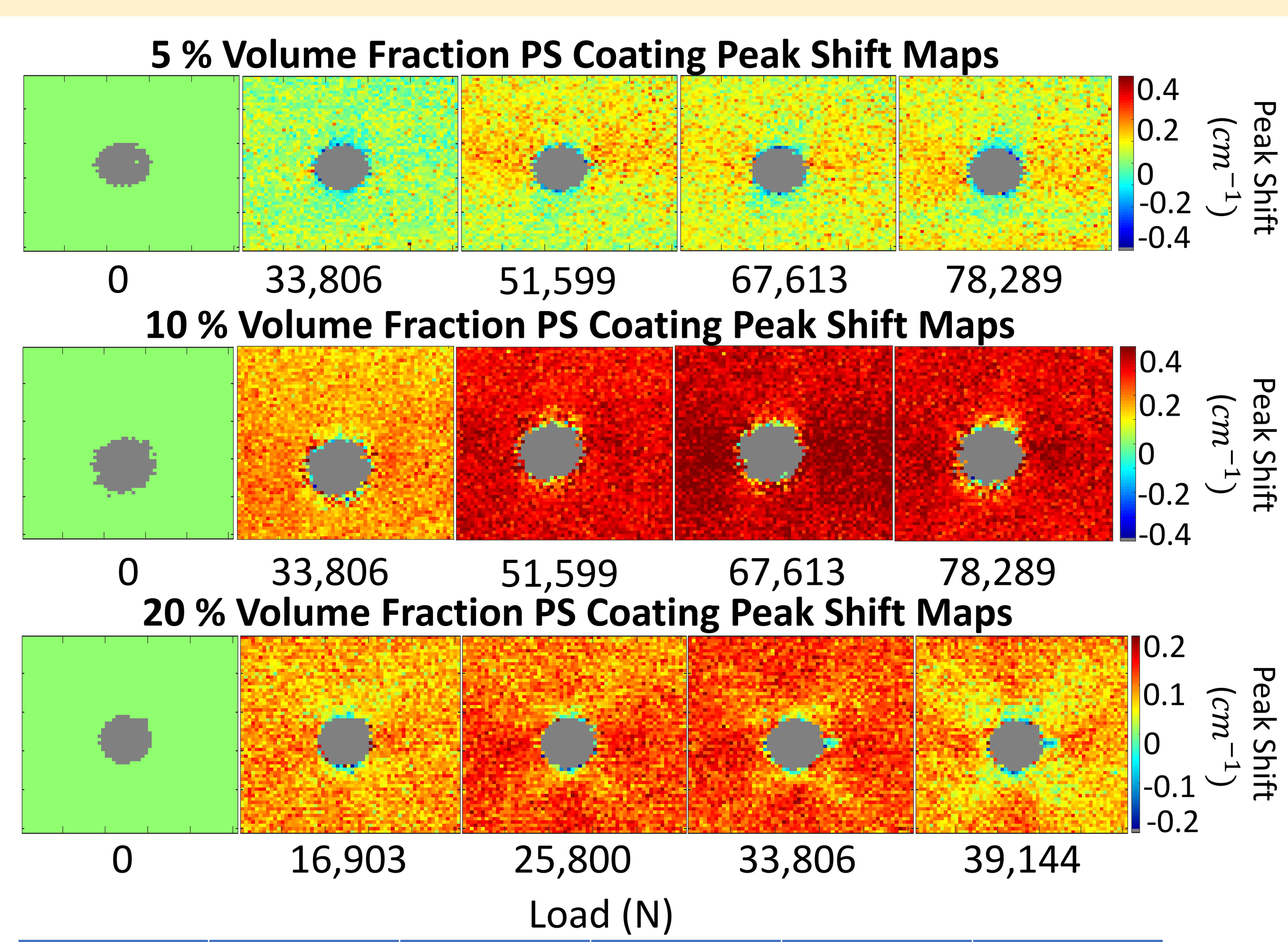
- The PS coatings were manufactured by embedding α-alumina nanoparticles with 99.8 % purity into an epoxy matrix.
- Three PS coatings were made with the following volume fractions of α-alumina nanoparticles: 5%, 10%, and 20%.
- The hard laminate specimens were coated with 5% and 10% volume fraction PS coatings and loaded up to 88,964 N.
- The soft laminate specimen was coated with 20% volume fraction PS coating and was loaded up to 44,482 N.
- The coated specimens were loaded in tension at a rate of 0.02 mm/sec and scanned with a Neon-Argon laser source using PLPS.





PS Coating Volume Fraction	Laminate Type	Elastic Modulus	Load rate	Total load applied	Measured area	Spatial Resolution
5 %	Hard	91 GPa	0.02 mm/sec	88,964 N	25.4 mm²	0.4 mm
10 %	Hard	91 GPa	0.02 mm/sec	88,964 N	25.4 mm²	0.4 mm
20 %	Soft	38.6 GPa	0.02 mm/sec	44,482 N	25.4 mm²	0.4 mm

Tensile Test Results



PS Coating Volume Fraction	Laminate Type	Collection Time per Point	Total Collection Time	Median Coating Luminosity	Median SNR
5 %	Hard	500 ms	32 minutes	8,529 counts/sec	42.85
10 %	Hard	200 ms	14 minutes	25,013 counts/sec	58.05
20 %	Soft	100 ms	8 minutes	104,698 counts/sec	94.27

- Peak shift maps for the 5% volume fraction PS coating begin to show noticeable shifts at a tensile load of 51,999 N.
- Peak shift maps for the 10% volume fraction PS coating exhibit significantly higher peak shifts at a tensile load of 51,999 N.
- Peak shift maps for the 20 % volume fraction PS coating show that, at 39,144 N, down shifts correlating with reduction in stress occur adjacent to the open hole.
- With higher volume fractions of α-alumina nanoparticles in PS coating, higher median SNR and median luminosity can be obtained, which correlate with better signal quality.
- Specifically, higher median SNR and median luminosity indicate less uncertainty in peak positions and smoother R-lines.

Conclusion

- For the hard laminate specimens, the 10 % volume fraction PS coating is more sensitive to the changes in stress than the 5 % volume fraction PS coating.
- The 20 % volume fraction PS coating on soft laminate showed more distinctive stress contours on the peak shift maps than the other two PS coatings on hard laminate due to:
  - It having the highest median SNR and median luminosity.
  - The soft laminate experiencing more progressive damage before failure than the hard laminate.
- PS coatings can detect different failure modes that are specific to the substrates' laminate type.

Future Work

- Future experiments will include investigating the effect of varying α-alumina particle sizes on the PS coating's sensitivity to changes in stress.
- Subsequent experiments include studying load transfer mechanics of the PS coating using PLPS.

References and Acknowledgement

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