# 3D Printed Stress Sensing Coating on Composite Materials

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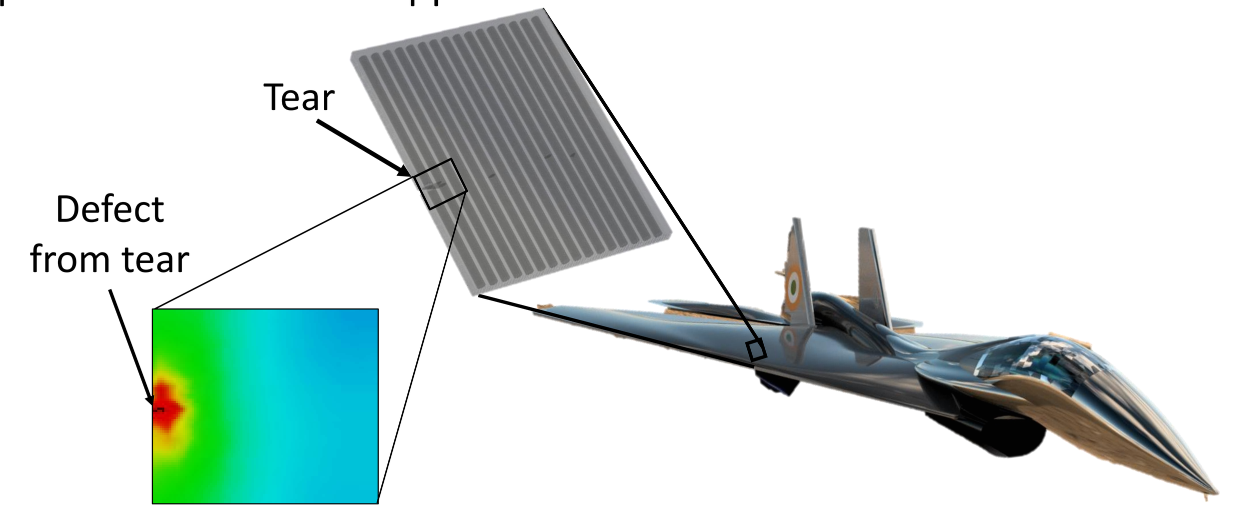
## Motivation

Carbon composite materials are commonly used in aircraft components in the aerospace industry due to their high strength-to-weight ratio and resistance to fatigue. New and improved carbon composites are being tested for improved structures. Non-invasive characterization methods with high spatial and stress resolution are needed to extract vital information from typical mechanical tests and reduce the time taken to qualify these materials for structural use. 3D printing has paved the way for easy application of customized sensing materials that, when combined with optical techniques, can create powerful sensors to support these mechanical tests.




Detecting a defect within the composite material

## Objectives

A method for 3D printing a quick and easy gage on composite specimens to provide high resolution stress and damage information is presented in this work.

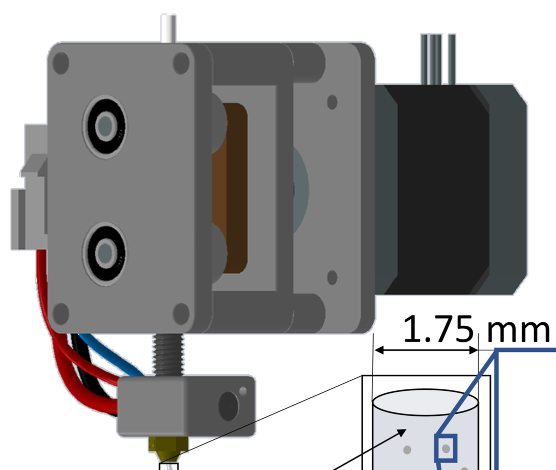
## Piezospectroscopic Filament

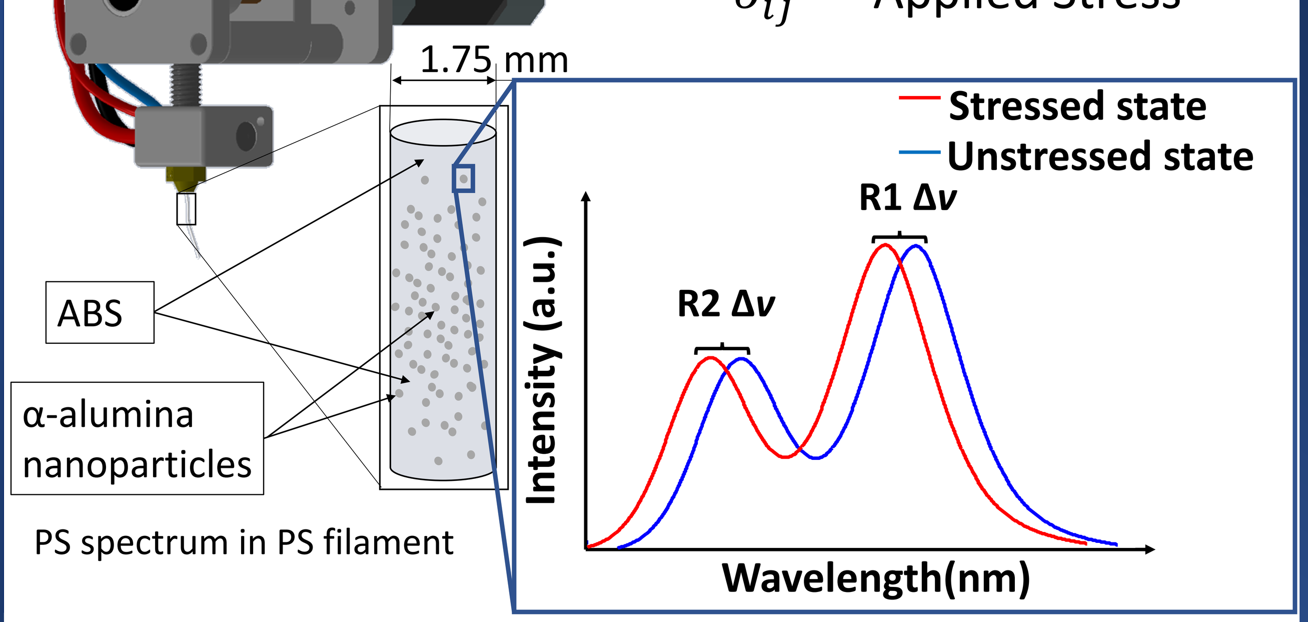
- The photo-luminescent spectrum forms due to excitation of the chromium ion impurities in aluminum oxide (α-alumina)
- The spectrum produces two characteristic peaks of α-alumina, R1 and R2, with wavelengths of 694.33 nm and 692.85 nm, respectively
- Shifts in the peak position are used in a tensorial relationship to obtain the stress

**Tensorial relationship**

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

- $\Delta\nu$ – Peak Shift
- $\Pi_{ij}$ – PS Coefficient
- $\sigma_{ij}$ – Applied Stress






PS spectrum in PS filament

## Mixing Procedure

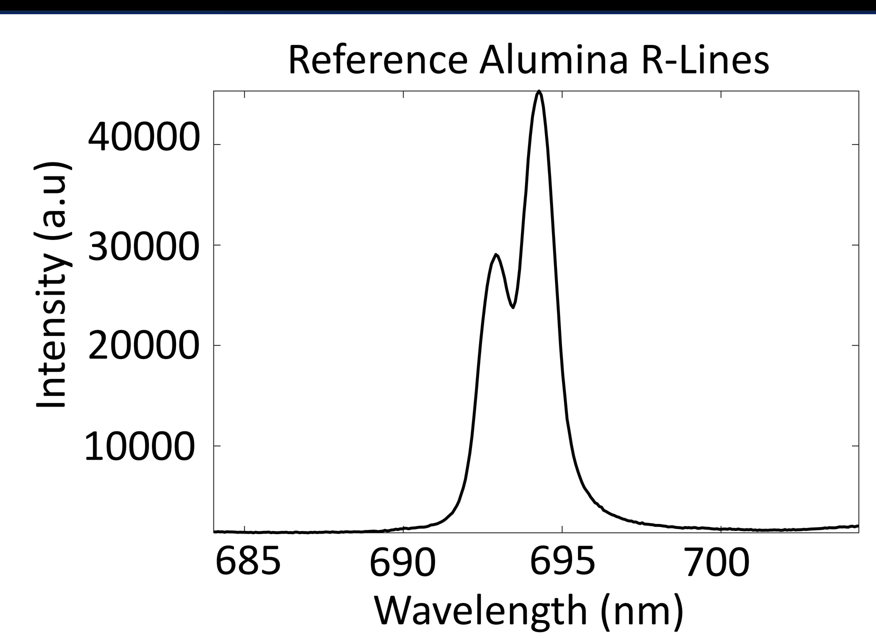
Images of the ABS, α-alumina, and acetone mixture being heated (left and middle) and mixed in a Thinky mixer (right)

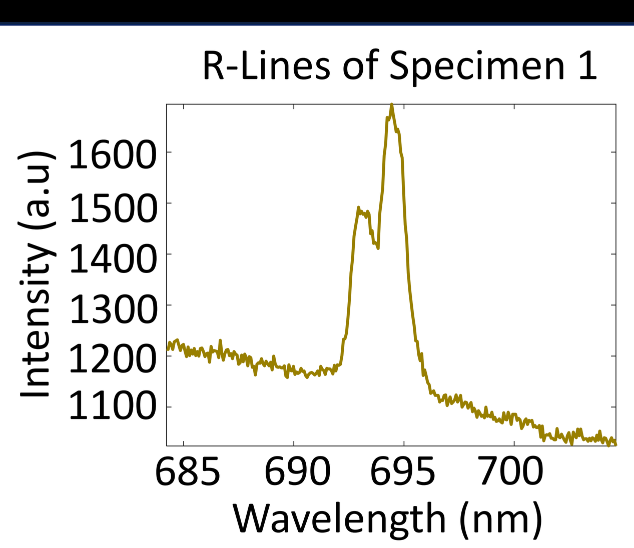
Images of the sonicator (left) and pressure desiccator-vacuum system (right)

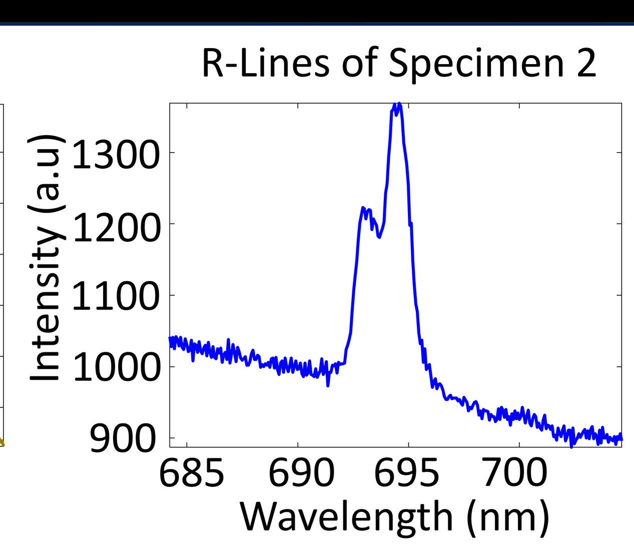
1. A mixture of 20 g of α-alumina nanoparticles and 180 g of ABS was weighed out to achieve 10 wt% of nanoparticles in ABS. This weight percentage is the maximum amount that can be used to ensure that the nanoparticles adhere well with the ABS.
2. The α-alumina nanoparticles were separated using acetone as a solvent.
3. ABS was mixed with acetone in a 1 g:10 ml ratio to create ABS juice.
4. Both the separated nanoparticles and ABS juice were mixed together with a Thinky mixer for ~30 minutes.
5. The mixture was placed into a sonicator for ~20 min to ensure homogeneity as well as remove any entrapped air bubbles.
6. The composite was placed inside a low-pressure desiccator vacuum system for ~45 min or until no air bubbles were visible. The most recent batch dried sooner than the allotted time.
7. The mixture was heated at the glass transition temperature of ABS (108°C). The outer layers of this mixture barely showed signs of melting during this process. Prior research indicated that implementation of ceramic nanoparticles would reduce the glass transition temperature ($T_g$), but that was not the case in this situation. Raising the temperature in increments of 5 °C for different parts of the mold resulted in no discernable differences.in the molds.
8. Its final form was unsuitable for filament extrusion, so four pieces were cut and selected as sample specimens to be used for verification of R-Lines.

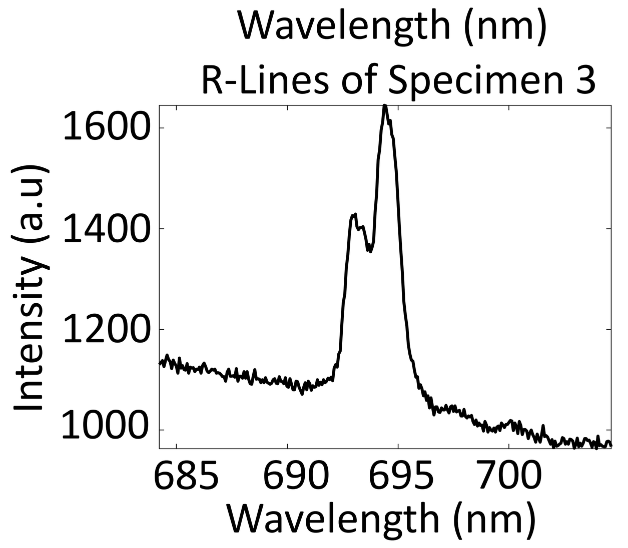

The four specimens of varying thicknesses to be used for verification testing

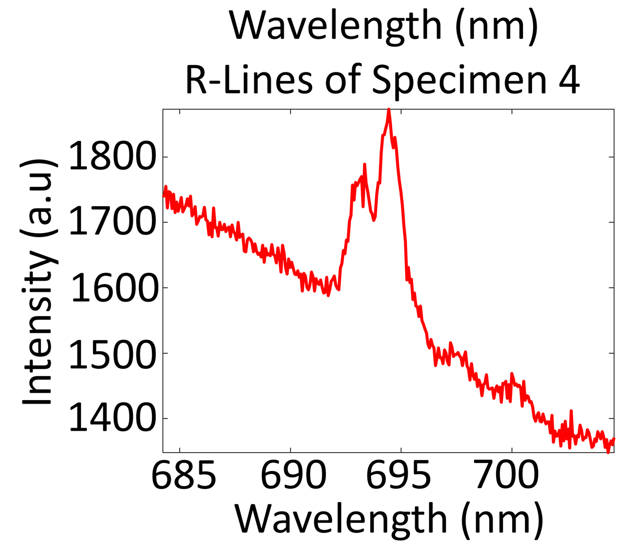
## Stress Sensing Verification

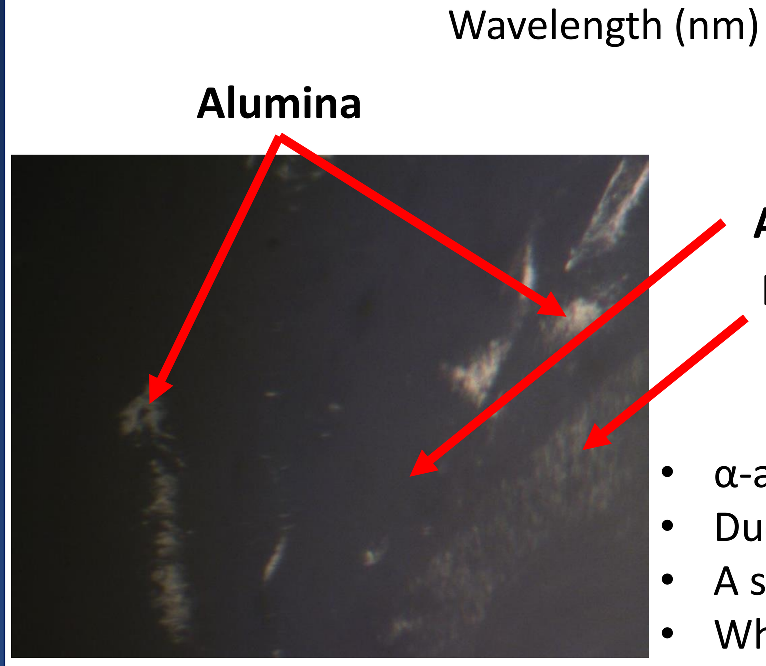



Optical Microscopy of Specimen 4

- α-alumina R-lines were detected in all specimens when performing piezospectroscopy (PS)
- Due to the small weight percentage, the R-lines have a weak signal
- A sloped baseline of unknown origin was observed from the scanned specimens
- When performing optical microscopy on the specimens, the ABS was observed to be translucent and have white speckles of α-alumina nanoparticles

## Conclusions

- α-alumina signals within the mixture were observed, making it suitable for stress sensing applications
- The current batch of the 3D stress sensing coating filament is not ideal for filament extrusion due to early drying and higher than predicted $T_g$
- The signal quality can vary greatly with some areas of the filament producing more noise in the data than others
  - This can be mitigated through a higher percentage of α-alumina nanoparticles throughout the filament
- Optical microscopy revealed that ABS is translucent after mixing, which indicated that ABS will cause little interference in stress sensing measurements.

## Future Work

**3D Filament Manufacturing Method Study**

- Conduct a study assessing the filament's mechanical and PS properties with different manufacturing processes
  - Thermal mixing allows for a higher weight percentage
  - The properties of ABS could be affected by the acetone
  - Bonding element to increase adhesion of the coating to the substrate
  - Characterize the properties of the filament due to the addition of the α-alumina nanoparticles

**3D Filament Optimization Study**

- Determine the optimal parameters for applying the filament as a coating in terms of:
- Layer thickness
- Mechanical properties
- Weight/Volume percentage of α-alumina nanoparticles.

**3D Filament Comparison Study**

- Compare the mechanical and PS properties of the 3D filament coating to other stress sensing coatings

## References & Acknowledgement

This work was supported by the National Science Foundation under Grant No. IIP 1701983 and the Office of Undergraduate Research at the University of Central Florida.

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