Fighting Vibrations With Vibrations: Towards Self Optimized Aerospace Structures

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Abstract:

A composite structure can be thought of as layers of material sandwiched together with advanced adhesives. Traditionally, composites are optimized based on quasi-static loading conditions by fabricating uniform patterns of fibers or particles in each layer. However, aerospace structures are exposed to vibratory loads. To this end, the objective of our project is to use vibration method to orient the fibers during the fabrication process to create composites capable of resisting vibration damage in the frequency range of flight envelope spectra. Through vibration control of the frequency and amplitude, fiber patterns can be manipulated into specific shapes based on the structural modes. The process for fabricating vibration driven composites is achieved by means of the classical Chladni plate experiment. Via a system of a vibrating plate and scattered particles, patterns coalesce at the nodes of the standing waves induced in the plate. This approach is advantageous since the nodes are areas of high stress concentration. Therefore, the particles gravitate towards the areas where structural reinforcement is actually needed. Strengthening the material at the nodes will reduce the structures susceptibility to damage due to cyclic loading. The experimental results show ideal patterns can be made via a testing apparatus with a level stainless steel plate suspended above a shaker. Initial testing showed the need for the creation of an analytical model and the use of finite element method to illustrate the nodal patterns and predict fundamental frequencies, which is still in development but has seen significant progress. The patterns achieved successfully using copper, carbon fiber, and homopolymer polyethylene, show that material of a more fine grain-like versus fiber-like nature proved to be easier to work with. Future work will revolve around perfecting the process of applying adhesive via a thermoplastic sheet.

Methods:

- Experiment with using melted homopolymer polyethylene and a thermoplastic sheet to see which is a better adhesive for creating the composite of material arranged in different Chladni patterns.
- Approximate the natural frequency of the plate using MATLAB and FEM.
- Create Chladni patterns with homopolymer polyethylene, diamond coated copper, and carbon fiber and record natural frequencies that produced them

Initial experiment with simple testing apparatus:

This test was a preliminary one to see the patterns we could get, but the screw in the middle was not ideal for making the composite.

220 Hz | 570 Hz

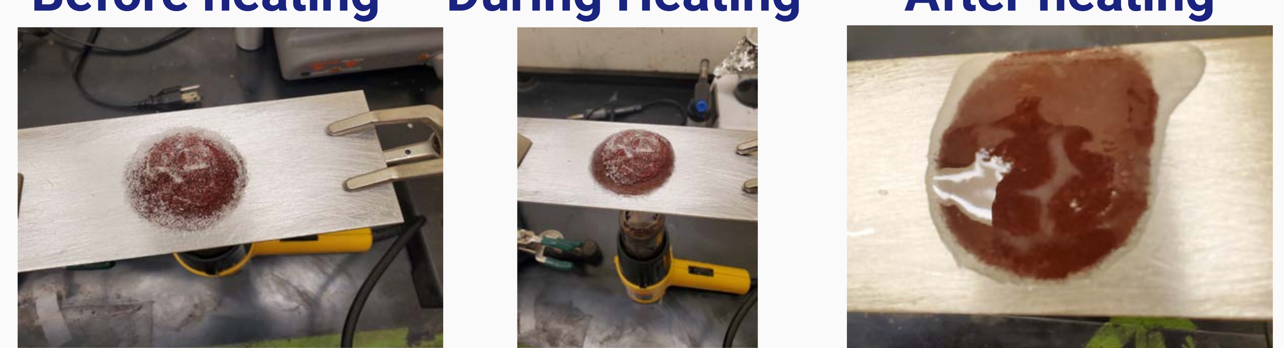
Homopolymer-Polyethylene

Carbon fiber

Heat gun experiment:

Before deciding on using a thermoplastic sheet for the composite, an experiment was done with heating up a mixture of diamond coated copper and the homopolymer.

Before heating | **During Heating** | **After heating**

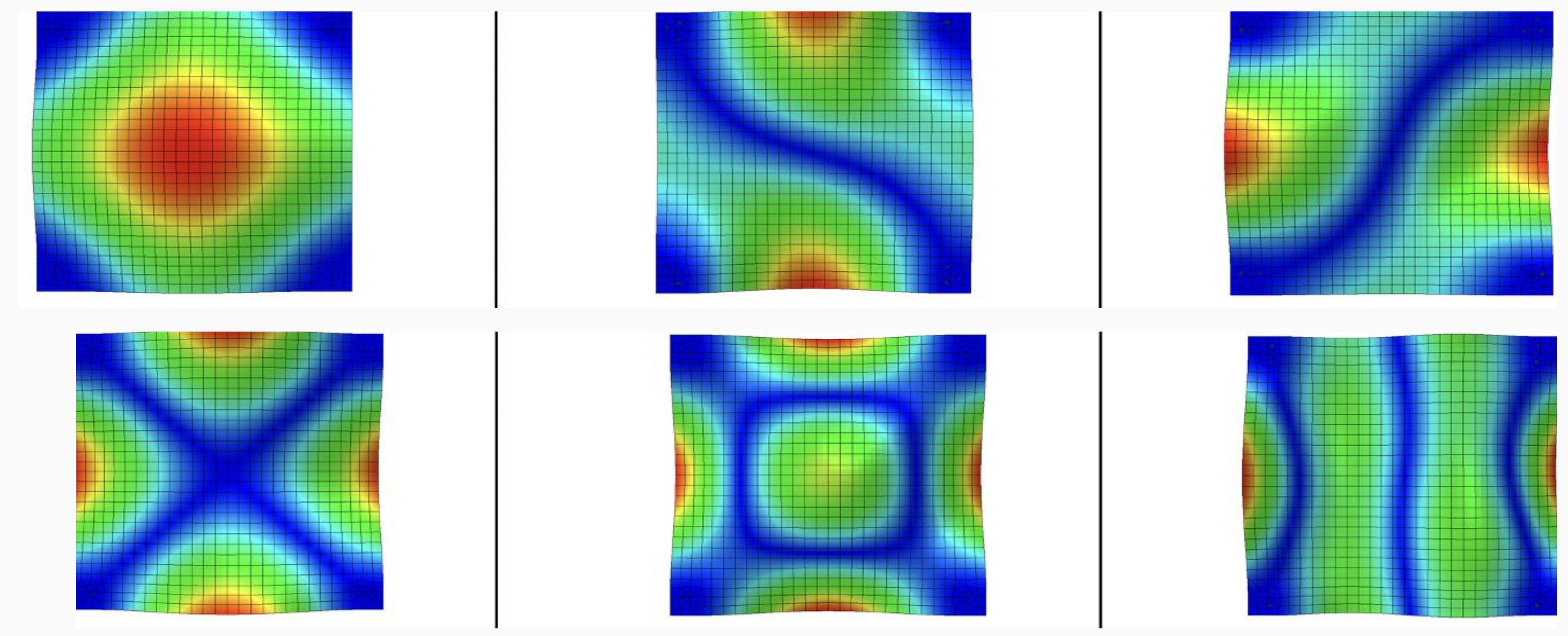


Final set up for shaker apparatus:

The final setup uses a MODAL shaker hooked up to an oscilloscope that vibrates the plate.

Finite Element Analysis model of the Chladni patterns:

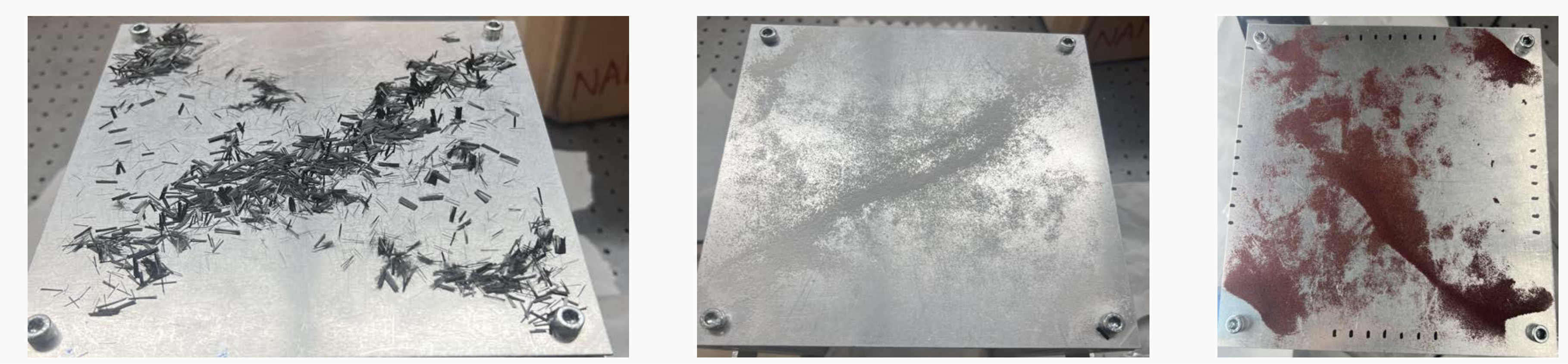
These are the models of the standing wave induced in the aluminum plate geometry. The blue lines are the nodes where the patterns forms.



First patterns produced on the thin aluminum plate:

This was the first set of data acquired, but as one can see it is unrefined compared to the model, so as such the apparatus was changed.

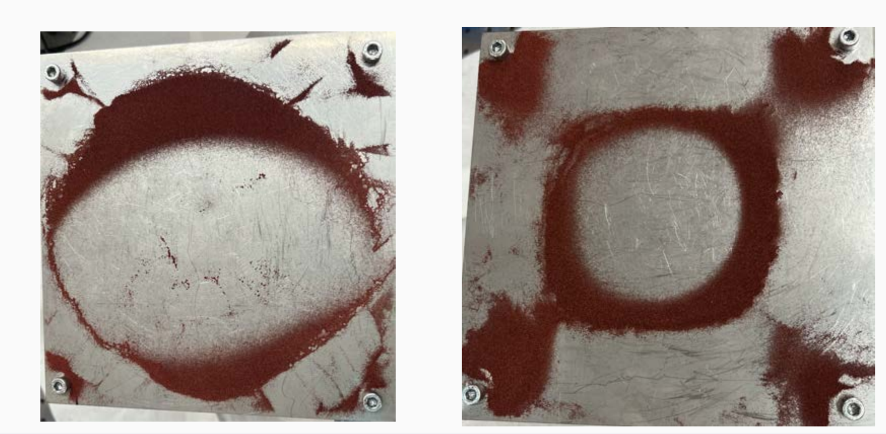
144 Hz | 145 Hz | 151 Hz



Patterns made on the thicker stainless steel plate:

66 Hz | 73 Hz | 85 Hz

110.9 Hz | 198.5 Hz



The patterns made on the steel plate proved to be more defined then the aluminum and as such a thicker steel plate is used in the final design. However, due to the plate not quite being level there is some room for improvement.

Conclusion:

The data shows that of the materials tested the diamond coated copper was the easiest to work with as the fine nature of the material makes it optimal for making the patterns. Carbon fiber works as well, but the fibers are prone to entanglement and makes the patterns slightly more difficult to produce and the homopolymer polyethylene has tendencies to stick to the vibration plate itself. The tests also show that making the patterns requires a slightly more rigid plate as the thinner aluminum plate was prone to bending in the middle causing the patterns to take on the less defined shapes. This project is still in progress, with the testing apparatus made and refined, the next steps are to do more testing to refine the data acquisition process and begin using the thermoplastic sheet to make the composite.

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