Preliminary Testing of Tank Track-Pad Meta-Material

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Biography

Before coming to Clemson University, I completed my undergraduate studies at Oglethorpe University, located in Brookhaven, Georgia, where I earned a BS in Physics. In tandem with completing my undergraduate work, I played four years on the varsity baseball team for the Stormy Petrels. I decided well before I completed my studies in physics that I wanted to pursue a Master's in Mechanical Engineering from Clemson, which would allow me to explore my interests in the aerospace and defense industries while developing skills necessary for an evolving engineering and design landscape.

Overview:

The work presented is a continuation of research presented by Neehar Kulkarni for using the "Unit Cell Synthesis Method" to develop cellular structure based meta-materials. The meta-materials designed were applied to a case study, investigating the use of said materials to replace elastomer track pads on the U.S. Army's Abrams Tank. While previous work concluded with the selection of an optimal track pad geometry, based on FEA analysis and the modeling of various designs under anticipated loading conditions, the current research intends to show the behavior of an additively manufactured pad, of optimal unit cell configuration. Preliminary results for simple static loading are presented and compared to the target response exhibited by the elastomer pad. From that data, conclusions are drawn and the opportunity for future work is revealed.

Motivation

The track system of the U.S. Army's M1 Abrams tank relies heavily on rubber elastomer pads located on both the inside and the outside of a metal track, which undergo near constant loading as the tank moves. A persistent problem for the crews who operate these tanks is the elastomer pads failing, resulting in an event similar to that of a car tire blowing out. Developing a titanium meta-material that behaves like rubber when loaded, yet still holds true to the desirable strength qualities of the metal, presents the Army with a feasible replacement pad that can withstand the rigorous stresses associated with everyday operation. It was not until recently, with the expansion of the additive manufacturing industry, that materials, such as these titanium pads, were able to be produced and implemented in modern day industry.

State of the Art

The interest in meta-material development is not isolated to the campus of Clemson, and the optimization of the meta-material design process is important for future development and research. However, the individuals or institutions using a design method like the "Unit Cell Synthesis Method", in regards to meta-materials, is limited to few if any outside of the Clemson and TARDEC communities, both of whom oversee this research. While many of the methods currently draw ideas from naturally occurring mesostructures or meta-materials, our method looks towards mechanical systems of beams and currently available beam geometries [1]. As for work directly related to the testing of the material, many of the testing conditions that we have implemented and plan to implement in the near future are generated by us, as an attempt to represent the specific interaction between track pad and wheel.

Intellectual Merit

The "Unit Cell Synthesis Method", according to the models, provides an opportunity for engineers to design meta-materials with non-linear deformation behavior. The testing of these meta-materials is crucial, not only for verifying the models themselves, but also for providing feedback associated with advanced manufacturing processes, such as precision additive manufacturing. Verification of the theory allows the method to begin to be applied to a multitude of different fields and real life challenges. It also provides details on the errors that might persist in a powder based manufacturing process, which is a manufacturing method that is garnering increased interest for it's ability to produce complex geometries. Finally, a greater general understanding of meta-materials and how they can take on the characteristic properties of other materials is critical to their increased utilization and design growth.

Broader Impact

The "Unit Cell Synthesis Method" can be seen as a way to create designer materials, intended to marry the best characteristic of multiple materials into one tangible. In the case of the track pad, having a titanium pad that behaves as rubber when deformed combines the high $E:\sigma_y$ (92.5:1) of the metal with the desirable non-linear deformation characteristics of the rubber. Ultimately, designer materials could be constructed as an attempt to extend the capabilities of materials in industry. These meta-materials exhibit enhanced physical properties while decreasing overall weight and geometric limitation, and while the current additive processes may come at a higher cost, future research and optimization can help to drive production costs down.

Research Approach

While the original research relied almost explicitly on modeling and computational analysis, which attempted to predict the loading responses of the material in question, the research we conducted was focused on experimental confirmation or contradiction. By testing a manufactured pad using a computer measured load frame, we were able to apply simple static compressive loads, ranging from 5kN to 22.5kN. The frame provided accurate measurements for the extension of the frame actuator at each load increment. A load cell would compute the responsive load generated by the extension into the pad. This ultimately yielded data points representing the position of the actuator with respect to the load being applied. We then took the total extension at each load increment and plotted them, which provided us with the graph that would tell us whether or not the pad behaved in a non-linear fashion.

Findings to Date

After our preliminary testing, it was determined that the track pad succeeded in following a non-linear deformation pattern under simple static loads. However, the target rubber response was not met, with the pad showing more than 20% strain at 1 MPa of applied pressure, only one half of the expected applied force needed to reach 20% strain. It was determined that under the loading conditions, a material with a nearly three times larger Young's Modulus would provide a response much closer to the target curve. Our findings have also driven us to investigate the effects of the additive process as a whole, and how the use of these powder-based materials effect the expected material properties.

Conclusions

Several conclusions can be drawn from the work completed over the last month. First and foremost, we confirmed that the meta-material designed through the "Unit Cell Synthesis Method" does in fact behave in a non-linear fashion when loaded and forced to deform, at least in the static loading case. However, we need to investigate some of the reasons for the discrepancies between the target response curve of rubber, and the generated curve based off of experimental data. By looking at the original model conditions, and the conditions of the loading experiment, perhaps we can identify the source of the error. We will also investigate the manufacturing process as a source of error, testing samples of the pad material under tension tests, to gain a more accurate value for yield strength and Young's Modulus, instead of using the solid state known values. But most importantly, with a proof of concept, we can expand our testing to analyze a larger portion of the track system, and explore the wheel itself as an area of future research and meta-material development.

References

[1] Kulkarni, N., Fadel, G., Li, G., Coutris, N., and Castanier, M. P., 2016, "Unit Cell Synthesis Method to Design Tank Track Pad Meta-material (under review)" J. Mech. Des., pp. 1-15.