SAND2022-14733C

Nonlinear Material Characterization in Dynamic Testing: Part II - Analysis

Samantha Ceballes[1], Moheimin Khan[2], Justin Wilbanks[2], Robert Kuether[2], Ben Pacini[2], Kyle Brindley[1], Manuel Vega[1], and Christopher Johnson[1]

[1] Los Alamos National Laboratory*
P.O. Box 1663, Los Alamos, NM, 87545

[2] Sandia National Laboratories**
P.O. Box 5800, Albuquerque, NM 87185

ABSTRACT
In this study, finite element modeling techniques are used to simulate and predict the dynamic response of a simple aluminum and foam stackup. Fixed base modes of the assembly are computed for multiple preload levels, and uniaxial vibration tests of this model are simulated using the commercial FEA tool Abaqus and then compared against Sierra. To capture the relevant physics resulting from these nonlinear sources and their corresponding influence on the structural response, Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) engaged in a collaboration to investigate and develop testing, analysis, and uncertainty quantification techniques. The present work is Part II of a three-part series and discusses the modeling and simulation approach taken to excite and identify the properties of a nonlinear, compliant material.

1 INTRODUCTION

In this effort, a "single-feature" testbed is proposed, with the overarching goal of reducing uncertainty in simulations and tests for complex systems and models by taking a bottom-up approach and isolating a feature or quantity of interest [1, 2]. Here, the quantity of interest is the dynamic response of a stiff material sandwiched between compliant materials, namely closed-cell foams. The compliant materials are nonlinear in nature and thus inherently alter the response of the center structure. By isolating the characteristic of interest while keeping other parameters simple and constant, sources of uncertainty due to the specified feature, a nonlinear, compliant material in this work, can be investigated. To attempt to isolate the characteristics of the compliant material, the testbed was designed with simple geometry. Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) established a collaboration to investigate testing, analysis, and uncertainty quantification techniques to characterize the dynamic response of the developed testbed. For the closed-cell foams of interest, their stress-strain relationship is nonlinear in nature and is broken up into three distinct regimes: (1) a low-strain stage, in which foam deforms in a linear elastic manner due to cell wall bending; (2) a plateau of deformation, at nearly constant stress caused by elastic buckling of cell walls; and (3) a region of densification, where the cell walls crush together, resulting in a rapid increase of compressive stress. These regimes and their effect on the response of the overall structure are studied here. This extended abstract is Part I of a three-part series that discusses the testing aspect of this work.

2 ANALYSIS APPROACH

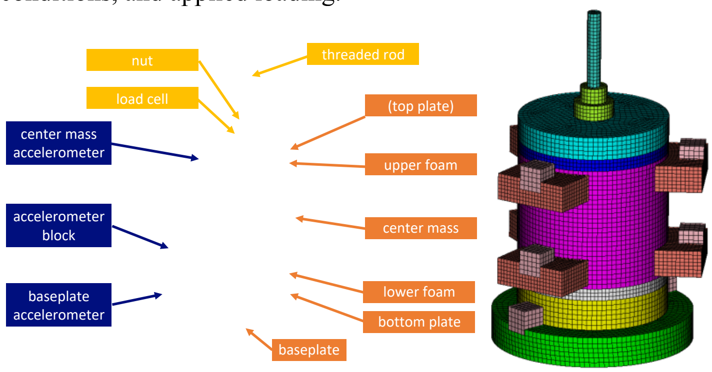
The finite element models utilized by both labs are nominally identical copies, which are shown in Fig. 1. The testbed components are uniquely labeled and used by each lab. The components of interest are the foam specimens

* Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA000001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

**Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

and center mass. The finite element model was built based off the corresponding experimental testbed, discussed in Part I of this series. The threaded rod holds the assembly together, and a load cell provides a method to measure and control the preload applied. The applied preload affects the localized stiffness of the compliant materials, leading to overall changes in the dynamic response of the component of interest: the center mass. To account for the effects of the foam material in the finite element model, the hyperfoam [3] model is used in both Abaqus (LANL) and Sierra (SNL). LANL and SNL finite element models reflect their initial approach to the research of complex response of a component due to nonlinear materials. LANL is leveraging Abaqus, a commercial FEA software, whereas SNL is utilizing the Sierra software suite [4–6]. A side-by-side comparison of the finite element models is shown in Fig. 1. The models, aimed at replicating the experimental setup, are similar in total mass, number of elements, number of nodes, applied boundary conditions, and applied loading.



(a) (b)

Figure 1. (a) LANL finite element model, and (b) SNL finite element model.

The goal of this work is to simulate the response of a simple aluminum and foam stackup. As stated previously, the LANL model was built using Abaqus commercial finite element software [4]. The 3D model assumes a fixed baseplate, which mimics the LANL experimental setup. The baseplate is located at the bottom of the testbed setup. From the baseplate up, the stackup consists of a bottom plate, a lower compliant foam specimen, a center mass (whose response is of interest), an upper compliant material specimen, and a top plate. Other parts include accelerometer mounts and accelerometers located on the baseplate and center mass. Lastly, the model includes a threaded rod that extends through the length of the testbed, a load cell, nuts, and washers. These components play a more functional role in the experimental setup and are included in the model to allow for direct comparisons. To simplify the model, counterbored holes and their associated fasteners in the accelerometer components were modeled as solid geometries. All surfaces were tied to one another. In total, the LANL model consists of 26 part instances, including two donut-shaped foam parts. The model was meshed using C3D8R elements, and general contact was implemented in the model.

The SNL model was meshed using CUBIT [7] and simulated using the Sierra finite element software suite. Sierra Solid Mechanics (Sierra/SM) [5] was used to perform the preloading, and Sierra Structural dynamics (Sierra/SD) [6] was used to perform the modal and random vibration analysis. A handoff procedure was used to take the final step from the Sierra/SM simulation and linearize it for the subsequent modal analyses. SD Hex8 elements, which are 8-node hexahedral elements with a selective deviatoric formulation, were used for the analyses.

3 RESULTS AND DISCUSSION

This work is still in the preliminary phases and, given the different boundary conditions and test approaches taken by each lab, not all analysis results are explicitly compared. Figure 2a shows the fit utilized for the hyperfoam material model for loading and unloading cycles in Abaqus and Sierra by LANL and SNL, respectively. The same foam specimen is used, and hysteretic trends are shown. Both simulations utilize this material model to determine the stress state after applying a preload and compressing the foams. While each group obtained different fit parameters, the models yield nearly identical static responses after preload. This agreement is demonstrated in Fig. 2b, where the strain after applying the preload step is plotted as a function of the applied strain. These results demonstrate that each simulation correctly applied the foam compression in their models. In Figs. 2c and 2d, the dynamic response of the testbed after compressing the foams is further investigated. It is shown that by increasing the compression of the foam specimen, the localized stiffness of the foam increases, thereby increasing the overall frequency of the structure. Additionally, it is shown that the foams appear to be stiffer in loading than they are in unloading. This result agrees with the stress-strain curves in Fig. 2a.

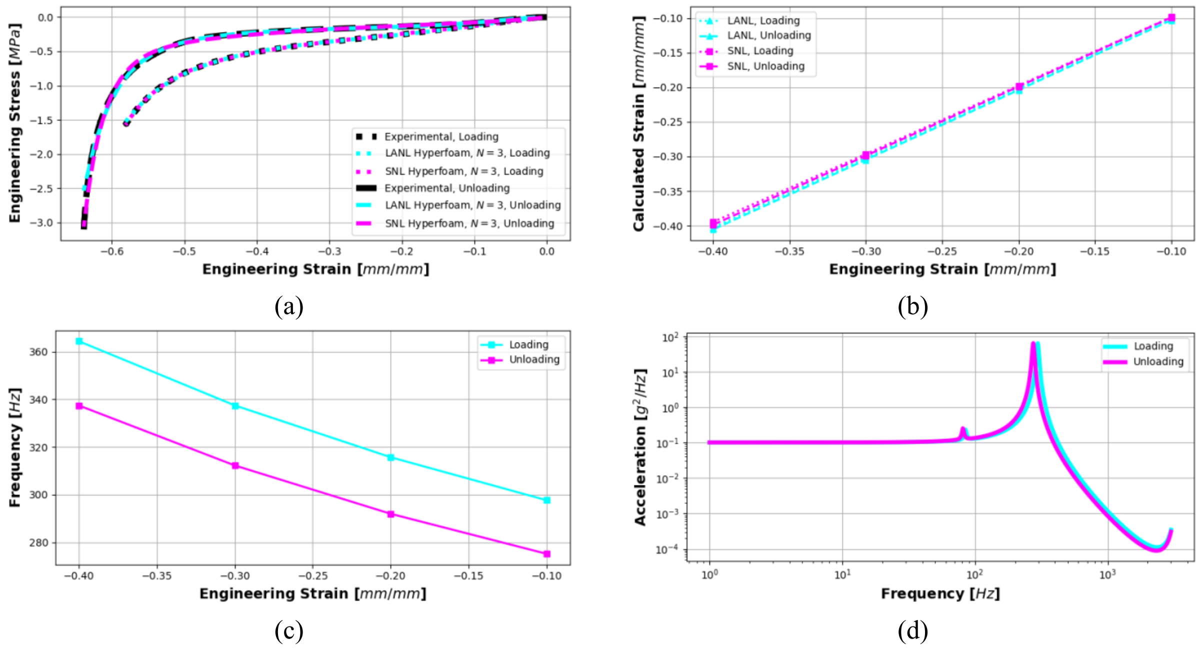


Figure 2. Analysis results showing (a) hyperfoam fitting of stress-strain curves, (b) calculated strain versus applied strain, (c) calculated frequency versus applied strain, and (d) acceleration response for loading and unloading cycles.

4 CONCLUSIONS

This extended abstract is Part II of a three-part series of collaborative efforts between LANL and SNL to characterize the dynamic response of a stiff component sandwiched between compliant materials with inherently nonlinear material properties. Thus far, the analysis efforts have focused on foam density and thickness studies, as well as variations in the applied preload to compress the foam specimens. The work is ongoing and will include further efforts in experiments, finite element modeling, and uncertainty quantification

Notice: This article has been authored by an employee of National Technology & Engineering Solutions of Sandia, LLC under Contract No. DE-NA0003525 with the U.S. Department of Energy (DOE). The employee owns all right, title and interest in and to the article and is solely responsible for its contents. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this article or allow others to do so, for United States Government purposes. The DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan https://www. energy.gov/downloads/doe-public-access-plan.

REFERENCES

1. Sheera S. Lum and Kyle A. Brindley. TRUST nonlinear dynamics (ND) report. Technical Report LA-UR-21-30732, Los Alamos National Laboratory, Los Alamos, New Mexico, USA, 2021.
2. Peter Meyerhofer and Elizabeth Martinez. Trust nonlinear dynamics testbed assessment. Technical Report LA-UR-21-29338, Los Alamos National Laboratory, Los Alamos, New Mexico, USA, 2021.
3. Twizell, E. H., and R. W. Ogden, “Non-linear Optimization of the Material Constants in Ogden's Stress-Deformation Function for Incompressible Isotropic Elastic Materials,” Journal of the Australian Mathematical Society, Series B 24, pp. 424–434, 1983
4. Dassault Systemés Simulia Corporation. Abaqus 2021. 2021. Providence, RI, USA.
5. SIERRA Solid Mechanics Team. 2022. "Sierra/SolidMechanics 5.10 User's Guide.". United States. https://doi.org/10.2172/1886996. https://www.osti.gov/servlets/purl/1886996.
6. Crane, Nathan, Day, David, Dohrmann, Clark, Stevens, Brian, Lindsay, Payton, Plews, Julia, Vo, Johnathan, Bunting, Gregory, Walsh, Timothy, and Joshi, Sidharth. 2022. "Sierra/SD - User's Manual - 5.10.". United States. https://doi.org/10.2172/1887938. https://www.osti.gov/servlets/purl/1887938.
7. CUBIT Development Team, “CUBIT Geometry and Mesh Generation Toolkit 15.8 User Documentation,” 2021, Sandia National Laboratories Technical Report: SAND2021-5152 W.