Impact Analysis of Additive Manufactured Elastomeric Lattice Structures

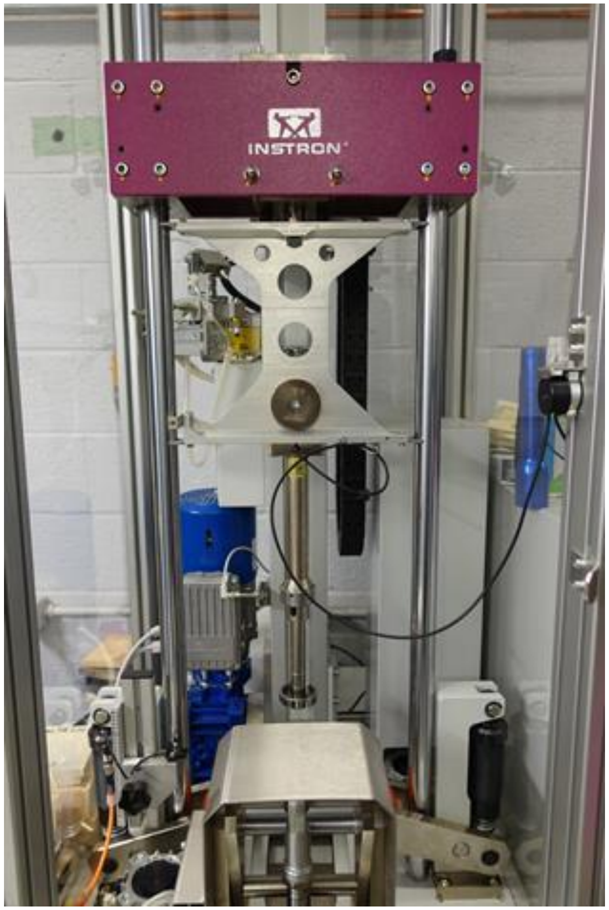
This project work was sponsored by the US Army's Natick Soldier Systems Center to investigate additive manufactured lattice structures for improved blunt impact protection for helmets. The idea is simple enough, modern helmets are designed to deflect or mitigate the impact forces due to bullets (high velocity) but not so much for blunt force impacts (lower velocity). In military operations, blunt force impacts are common, albeit sometimes, accidently due to falls or in the rush to enter-exit buildings and vehicles. In combat, flying debris also present challenge to helmet designers where the impacts can be both high- and low-velocity.

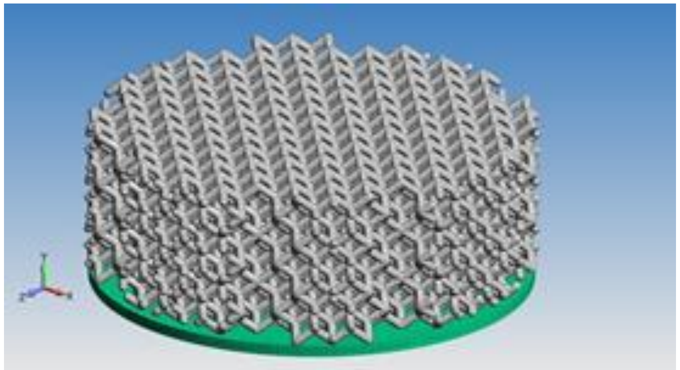
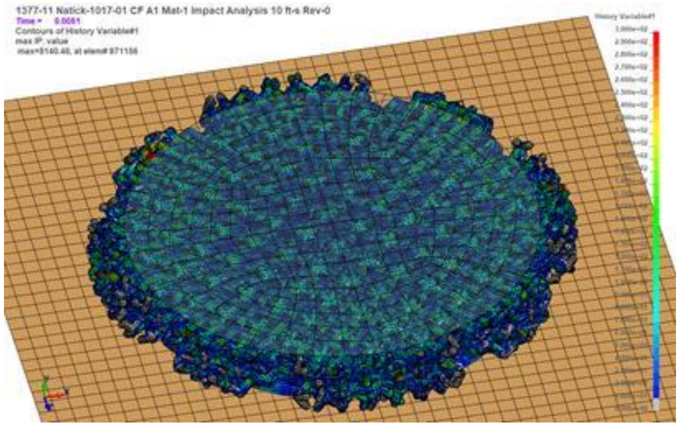
Our work was to set the foundation for the exploration of polymeric 3D lattice structures to create the next generation of energy-absorbing helmet liners for military applications. These structures could only be manufactured using the additive process and hence, the title of our work. Results from this study can be found in our publication: 1377_11-Natick-1017-01 LS-DYNA Analysis of Engineered Polymer Structures for Blunt Impact Protection Rev-0B.pdf.

The helmet's outer shell construction and geometry is fixed but modification to the interior foam structure is wide open

Impact Modeling of Additive Manufactured Structures



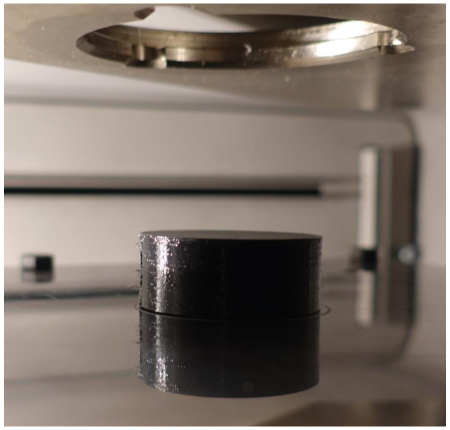
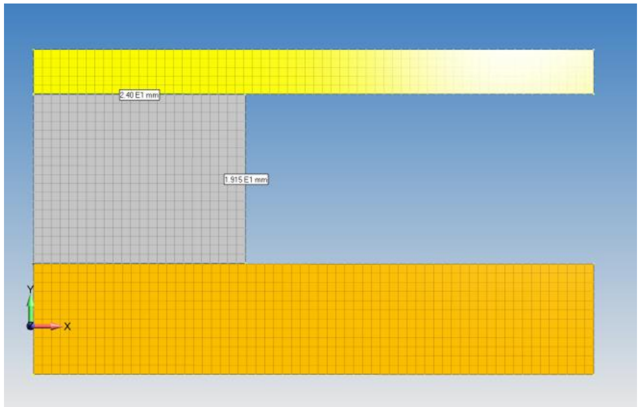
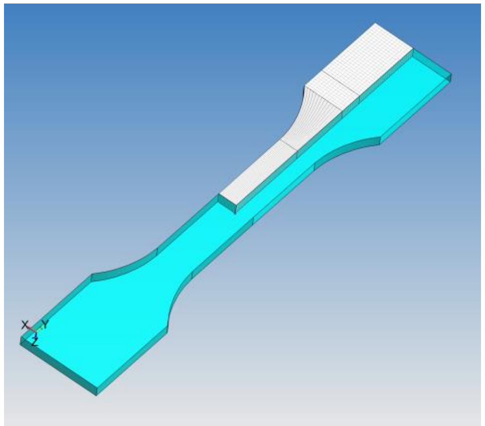


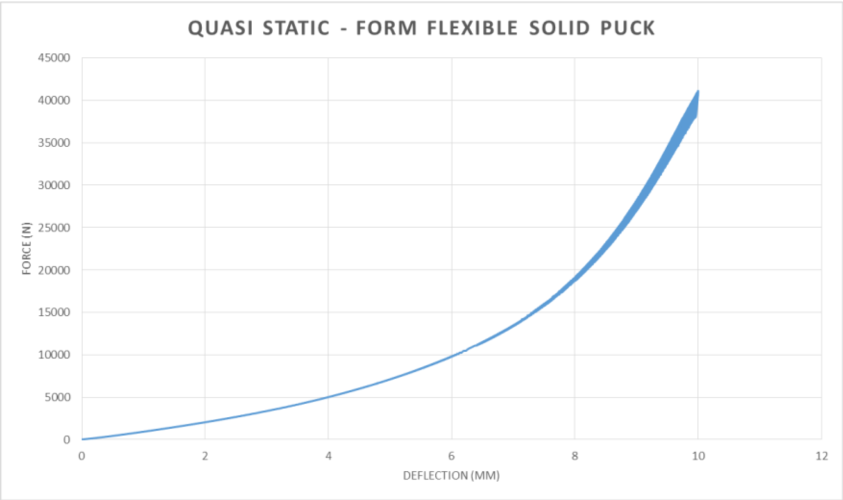
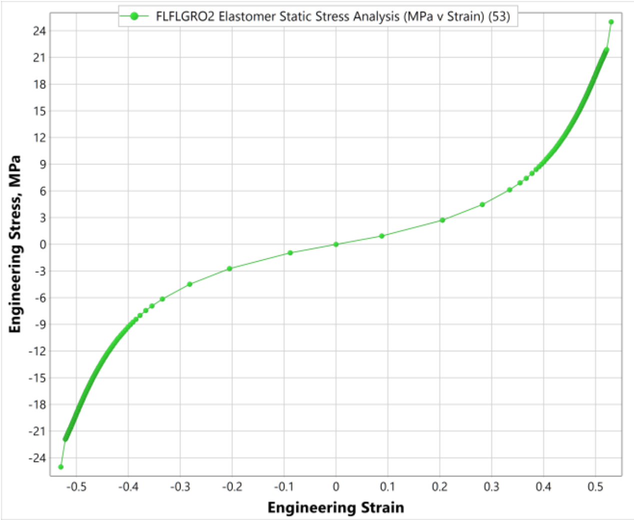



YouTube Video

A graphical overview of the project is available via this video: Nonlinear and Impact Analysis of Additive Manufactured Lattice Structures

Experimental Testing of Polymeric Compounds: Compression and Tensile Testing

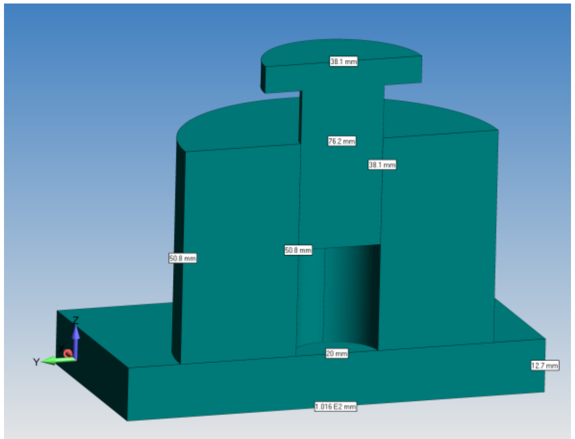
Raw Instron Data	FEA Model for Compression Testing	FEA Model for Tensile Testing
		

Initial Processing of Compression Data	Final Combination of Compression/Tensile Data
	

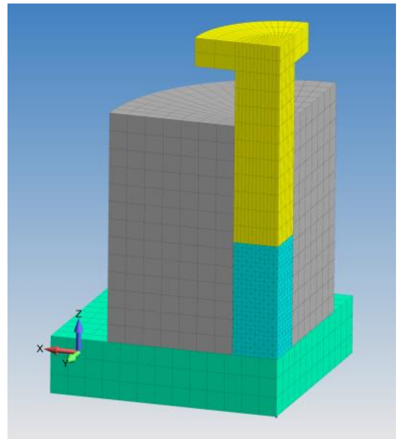
The program started with the gathering of standard static mechanical test data for the polymeric compounds that were to be used in the additive manufacturing process. For compression testing, 20 mm thick pucks were used. Likewise, tensile testing was done on 10 mm thick coupons. The data was then validated against a 2D axisymmetric model and a corresponding 3D model of the tensile test coupon.

Experimental Testing of Polymeric Compounds: Bulk Modulus Testing

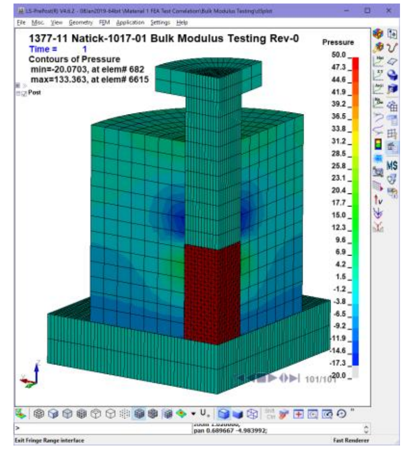
Bulk Modulus Fixture Geometry



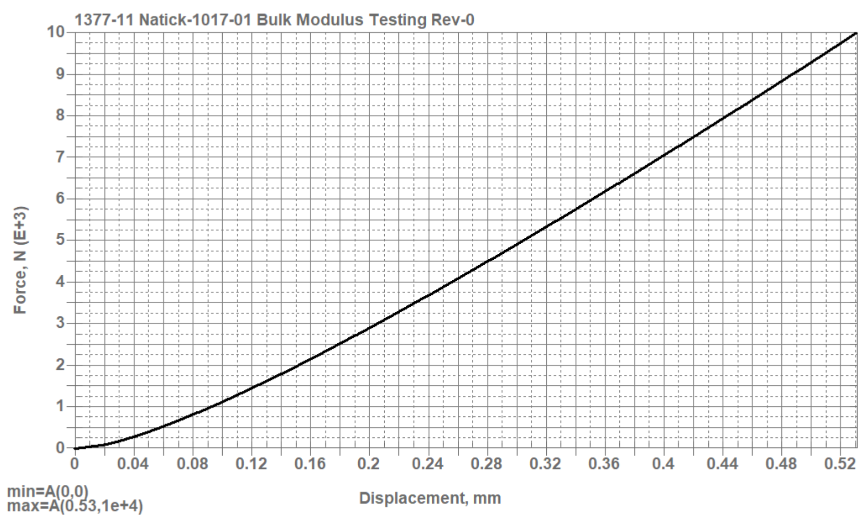
FEA Model for Bulk Modulus Evaluation



Bulk Modulus Results

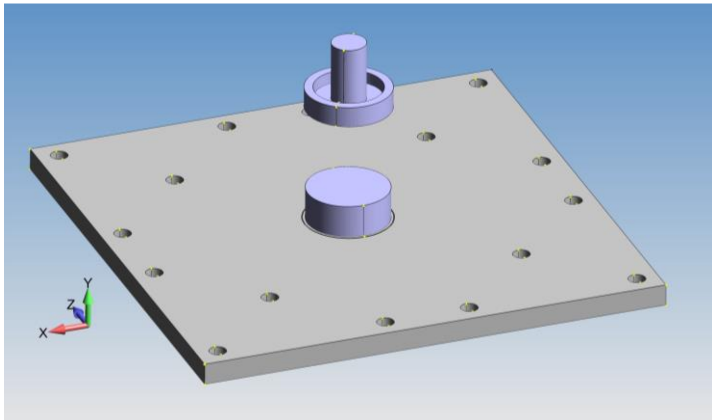
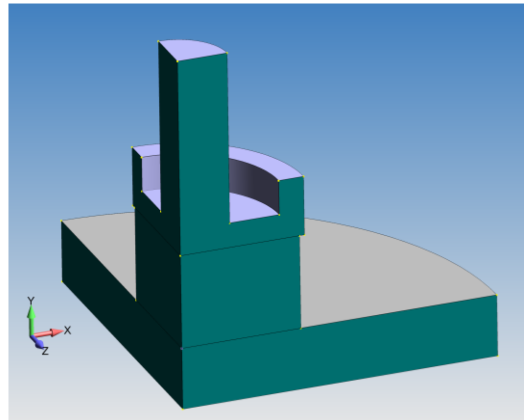
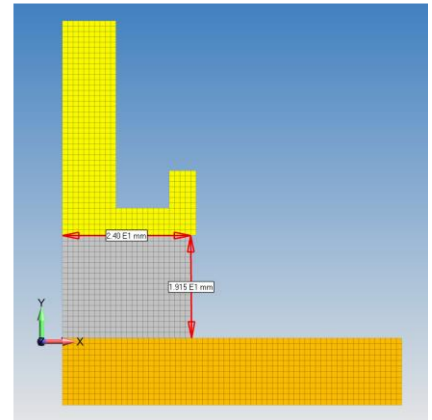


Force versus Displacement Response from Bulk Modulus Evaluation

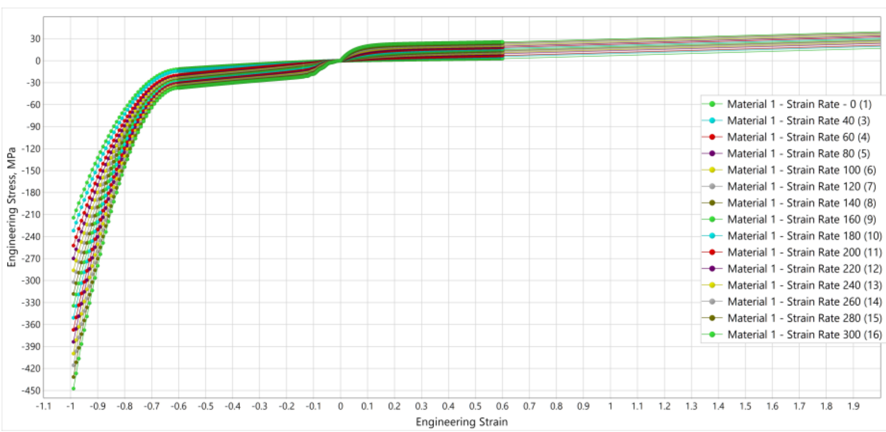


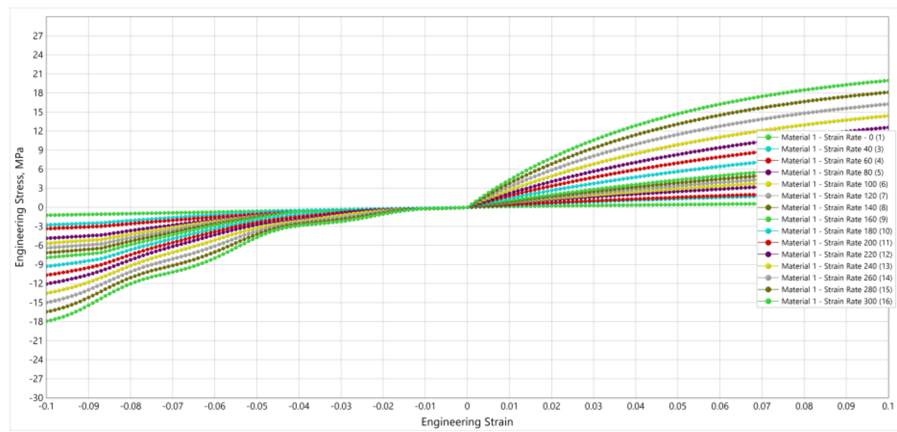
The last part of the static testing program was to measure the material's bulk modulus. This was done by manufacturing a simple fixture that could compress a chunk of the material. The fixture was a circular block with a hole drilled through it. A plunger was then pressed down against the sample. A FEA model was then built to mimic the experimental test.

Impact Testing of Polymeric Compounds: Dynamic Impact Tests

Experimental Impact Geometry Configuration	Idealization into FEA Geometry	Axisymmetric FEA Model
		

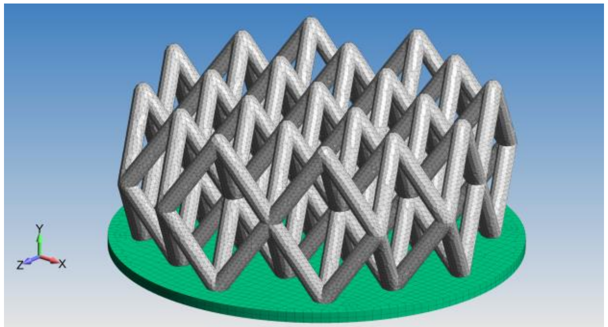
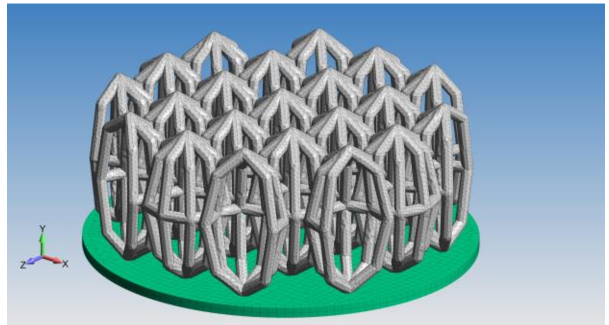
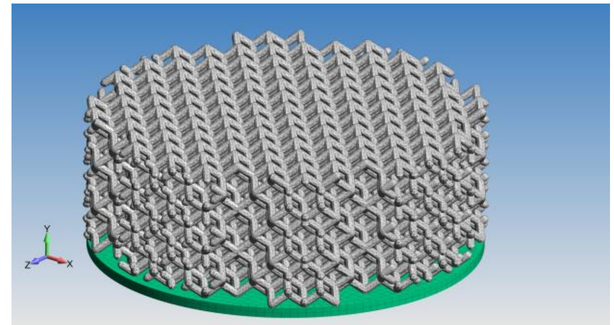
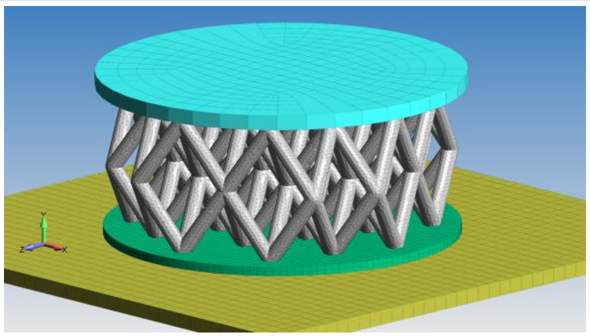
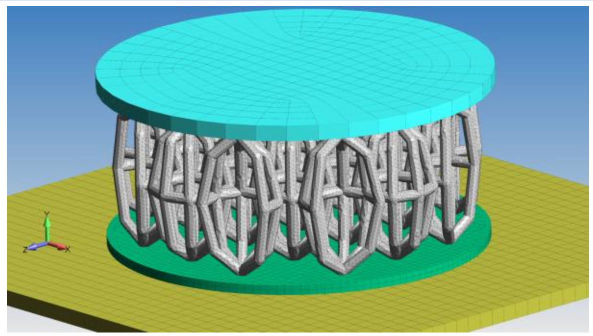
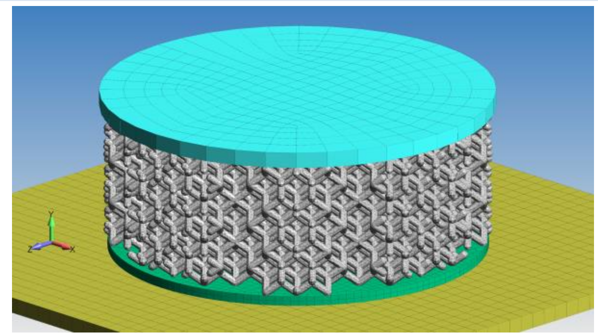
*MAT_181 Engineering Stress v Strain as a Function of Strain Rate



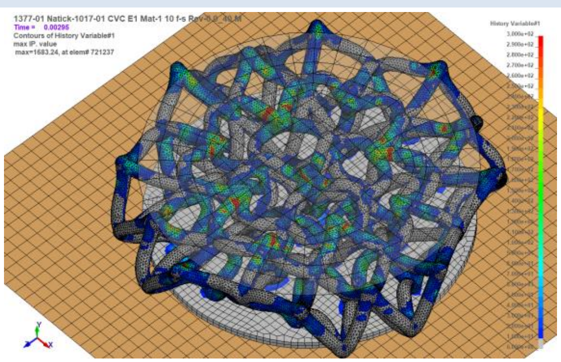
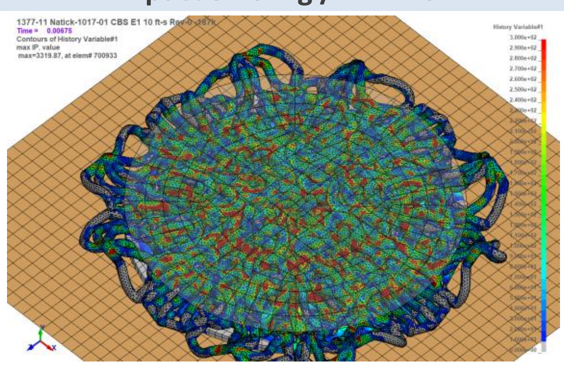
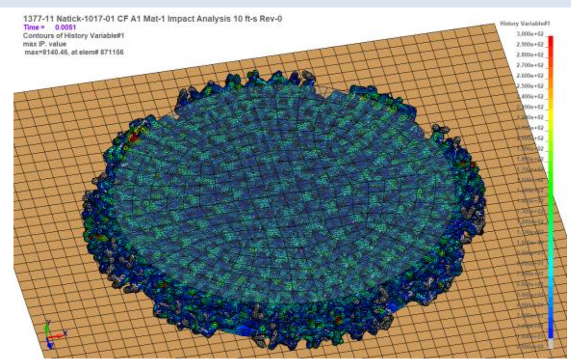


Impact tests were performed on thick (20 mm) pucks under varying strain rates. The impact data was combined with static compression, tension and bulk modulus tests to arrive at a set of engineering stress versus strain curves. Obviously, these curves represent hand-smoothed data that could then be used for input into LS-DYNA's *MAT_181 simplified rubber material law.

Energy Absorption Characterization of Additive Manufactured 3D Lattice Systems

CVC E1	CBS E1	CF A1
		
FEA Model – 145k Nodes / 647k Elements	FEA Model – 180k Nodes / 770k Elements	FEA Model – 381k Nodes / 1,510k Elements
		

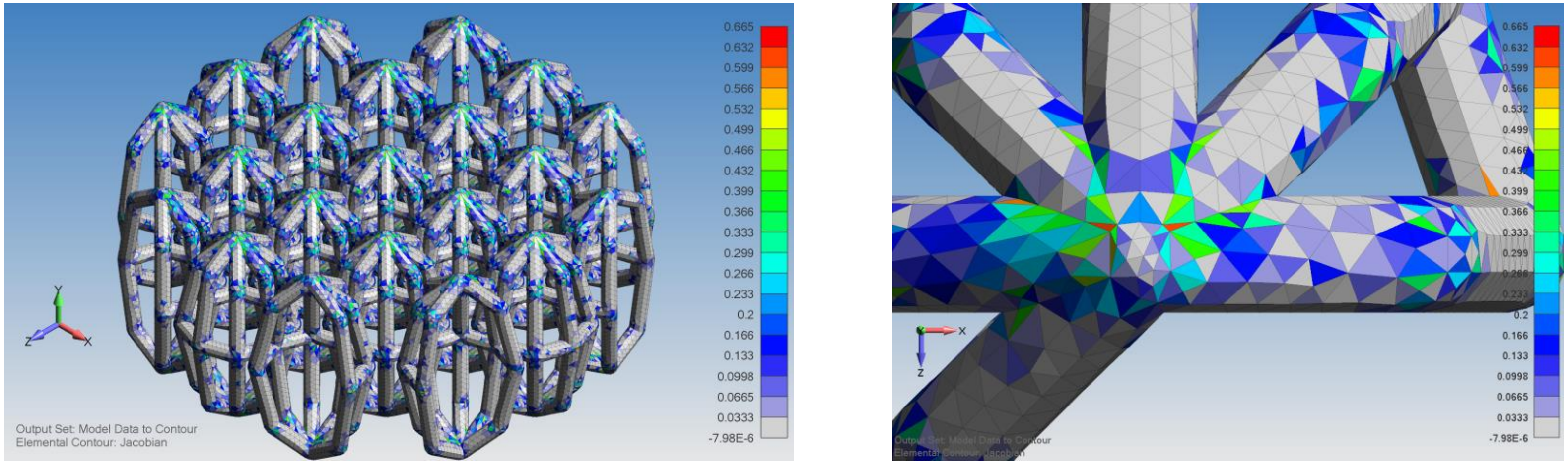
Impact 3.104kg / 4.2 m·s^{-1}

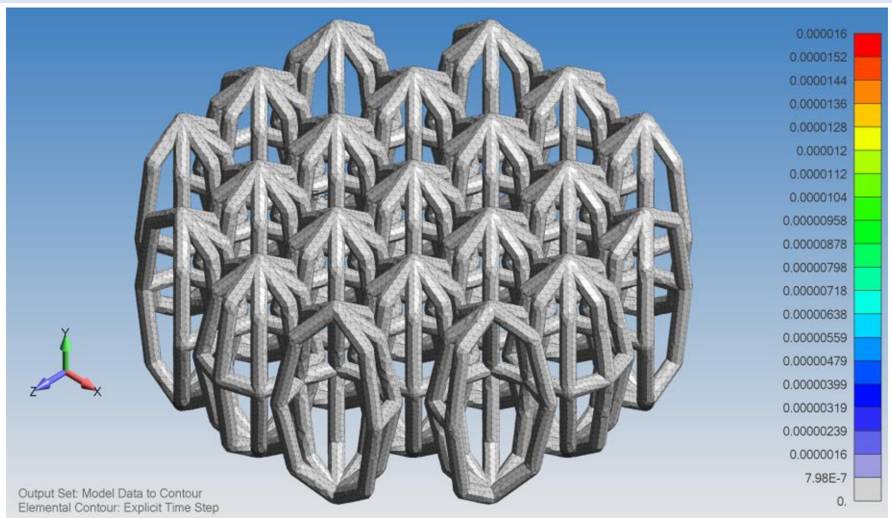
FEA models were created from 3D lattice geometries and virtually impacted.

LS-DYNA FEA Modeling Details

Element Quality Check (Jacobian)



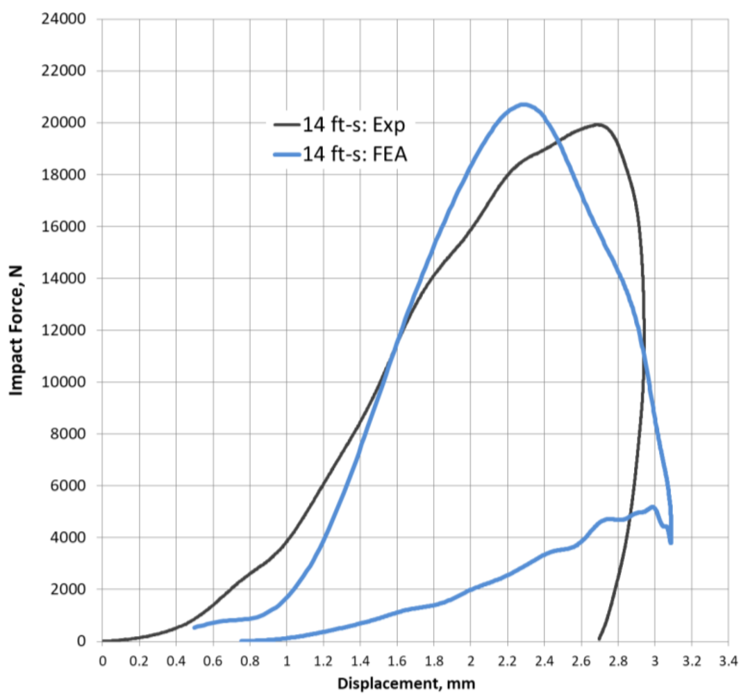
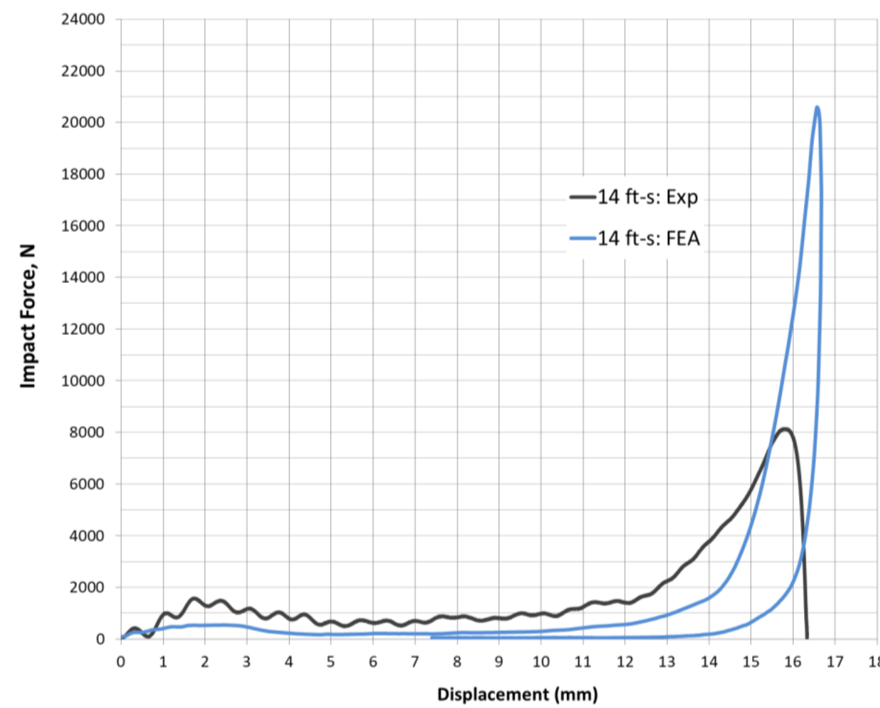
Explicit Time Step



One of the challenges of this work was mesh convergence. Given the elastomeric material response (*MAT_181) and severe impact force, a mesh quality and convergence study was required. A series of were then made to finally arrive at a mesh density that would provide consistent impact forces with minimal negative sliding impact energy.

Impact Test to FEA Correlation: Part I

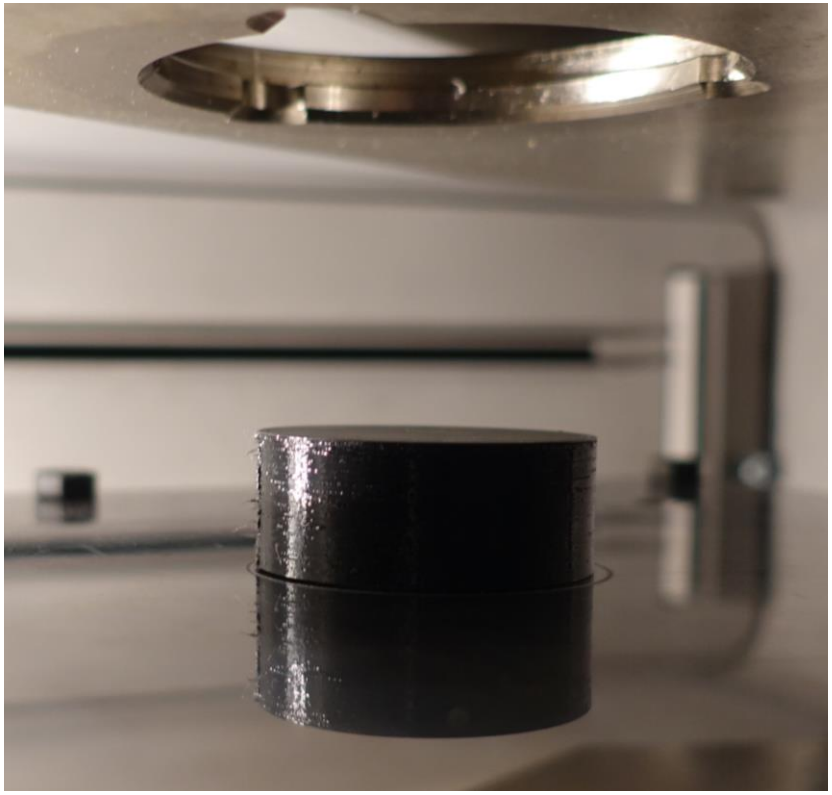
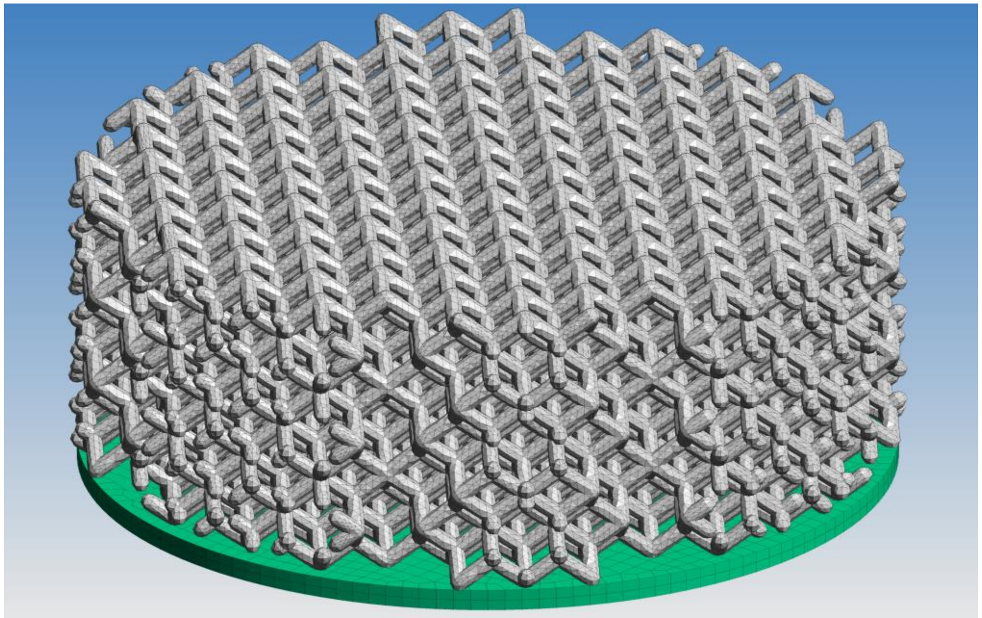
Dedicated Material Law, Quality FE Mesh, Precise Experimental Data = Absolutely Terrible Validation

Material Law Coupons: Exp to FEA	Additive Manufactured 3D Lattice Structures: Exp to FEA
	

The material law development correlated beautifully to the FEA models through the complete range of impact velocities that were investigated (10, 14 and 17 ft·s^{-1}. For direct comparison, only the middle impact velocity (14 ft·s^{-1}) is presented for comparison against the goal of this project, that is, to predict the impact response of additive manufactured lattice structures. As shown in the right-hand side graph, the experimental results provided a maximum impact force of 8,000 N while the FEA model calculated an impact force of nearly 21,000 N. This discrepancy can't be swept under the rug or simply explained by modeling assumptions or perhaps numerical limitations. That is, the model is known to work well (i.e., material law validation) but when compared to the additive manufactured structure, it is hugely different, as if the mechanical properties of the material had changed during the additive manufacturing process?

Impact Test to FEA Correlation: Part II

What We Now Know Is Not What We Thought We Knew

Material Data from 50 mm Diameter Blocks	Impact Test Articles are Lattices of 1 mm
	

The key finding from this FEA consulting project was that standard material characterization procedures would have little value in the development of FEA material laws for additive manufactured structures. It now seems somewhat obvious when comparing the scale of the test coupons (cm's) against that of the lattice structures (mm's) that material properties might change due to manufacturing but it was never expected that the change would be so dominate to invalidate the work. Although this project ended without the desired result, it did open the door to a whole new line of investigation on how best to characterize polymeric additive materials which will be a subject of another funded project in the near future.


PROJECT EXAMPLES
OUR SERVICES
FAA 16g sled test validation
Femap FEA Model
FEA + LS-DYNA Model
Validation is Gold
Stress and Vibration Analysis of Large Composite Container
LS-DYNA turbine burst simulation
BOEING
FAA
CFD study on co-generation power plant building
FEA
CFD
LS-DYNA
ASME BPVC
FINITE ELEMENT ANALYSIS
Predictive Engineering
Finite element analysis consulting services, software, training and technical support
• Composites, Pressure Vessels, Vibration
• NASTRAN: Linear Dynamics
• LS-DYNA: Drop-test, Impact, Burst Analysis
• STAR-CCM+: Thermal/Flow Analysis