Optimized Design of Crumple Zone on Vehicles

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PROBLEM DEFINITION

This design project aims to modify the longitudinal beam component of crumple zones in cars to be more lightweight while maintaining safety through sufficient energy absorption, leading to reduced CO_2 emissions.

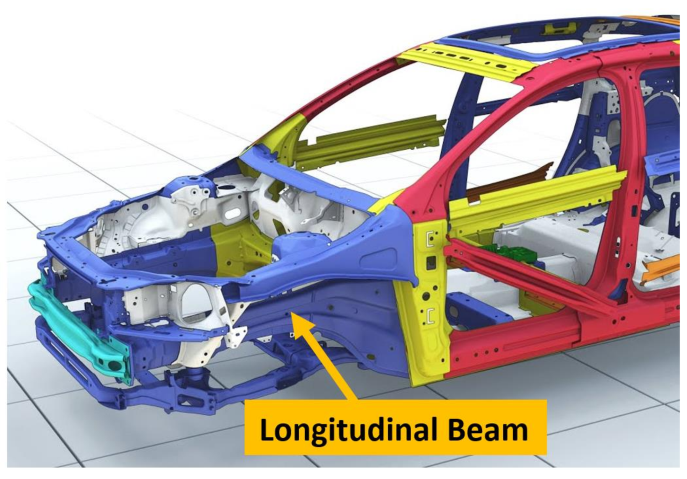


Figure 1. Crumple Zone of Vehicle Frontal Structure with Force Paths

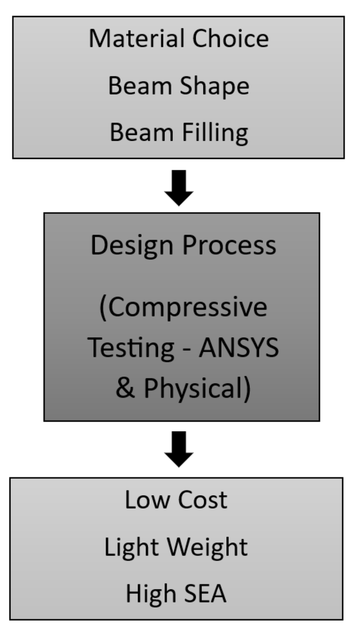


Figure 2. Longitudinal Beam Design Considerations

CONSTRAINTS

1. Computational Time and Expense
2. Use of Conservative Elastic-Perfectly Plastic Material Model (*Figure 4*)
3. 3D Printing Limitations Regarding Resolution and Material

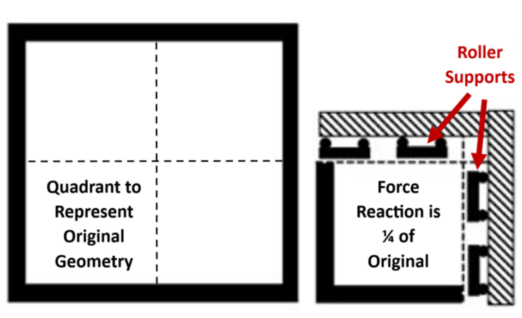


Figure 3. Diagram Showing Use of Symmetry in a Tube Model

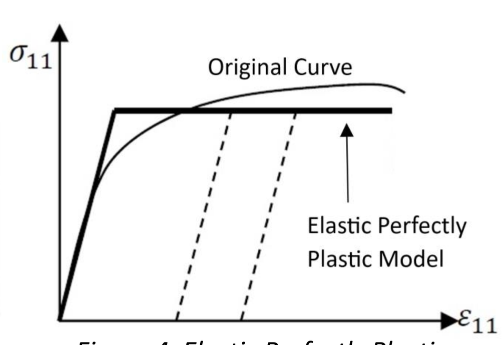
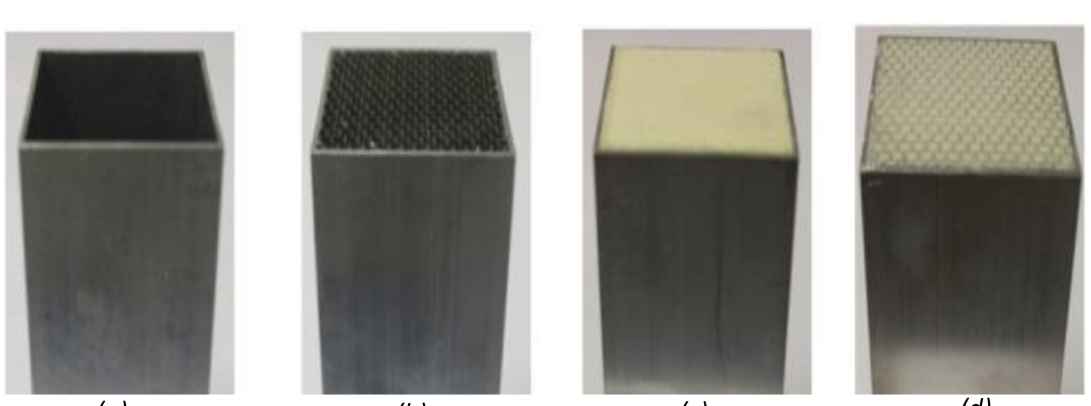


Figure 4. Elastic Perfectly Plastic (EPP) Material Model

PROPOSED DESIGN

- Honeycomb-filled and foam-filled longitudinal beam (*Figure 5d*)
- Aluminum alloys and polyurethane foam are optimal materials
- FEA simulations and experimental data has shown significant increases in specific energy absorption (SEA) and peak crush force (PCF) from fillings (*Figure 6*)



(a) (b) (c) (d)

Figure 5. (a) Square Tube (b) Honeycomb-Filled Tube (c) Foam-Filled Tube (d) Honeycomb and Foam-Filled Tube

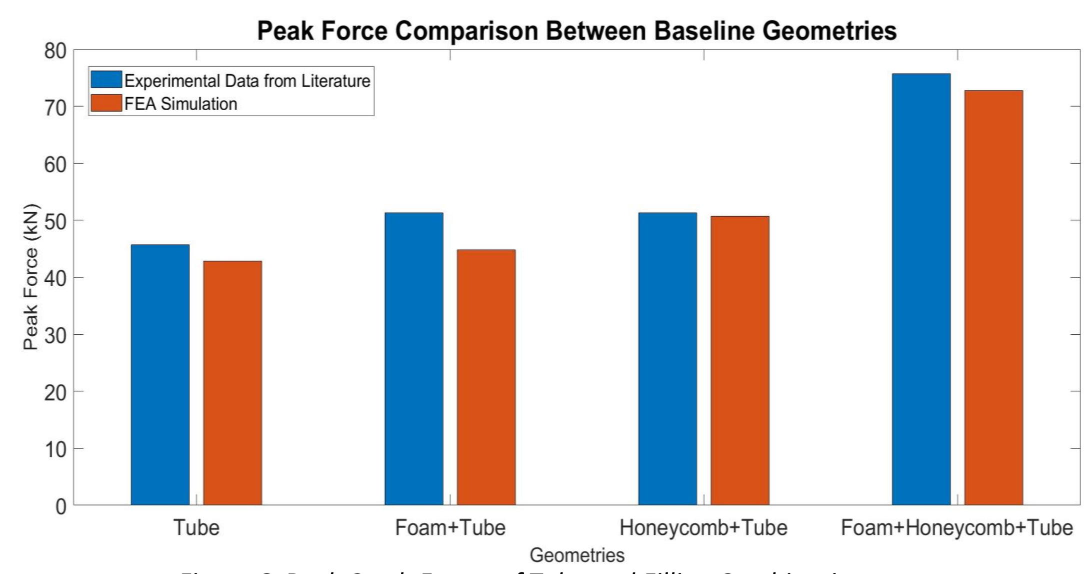


Figure 6. Peak Crush Forces of Tube and Filling Combinations

DESIGN DEVELOPMENT

- **Enneagonal tubes** (*Figure 7*) : Nine-sided tubes
- **Layered honeycomb filling** (*Figure 8*): Inner layers contain thinner cell walls and outer layers contain thicker cell walls
- **Functionally graded honeycomb filling** (*Figure 9*): Maximum thickness at corners of each honeycomb cell

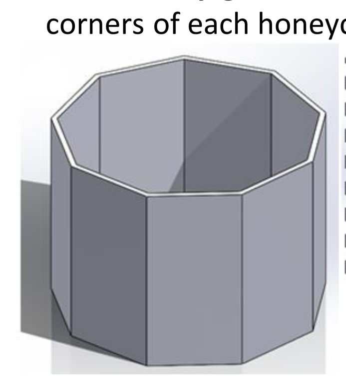


Figure 7. Enneagonal Tube

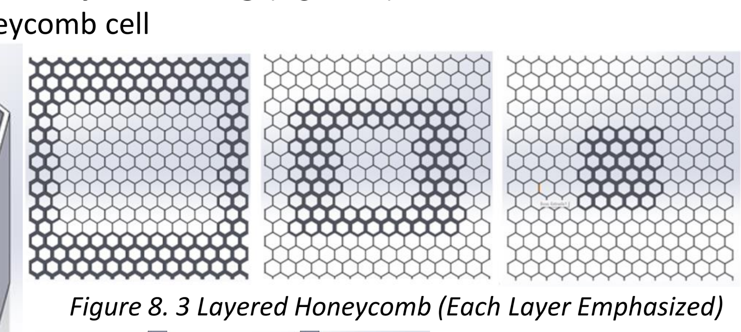


Figure 8. 3 Layered Honeycomb (Each Layer Emphasized)

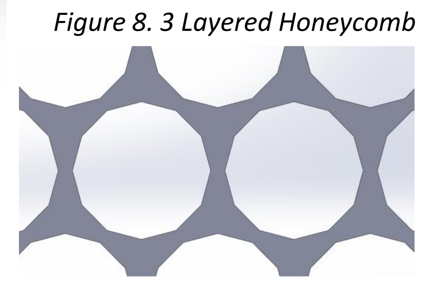


Figure 9. FG Honeycomb

TESTING CRITERIA

1. **Specific Energy Absorption (SEA) –** energy absorbed per unit mass
2. **Peak Crush Force (PCF)** - maximum reaction force from crushing model

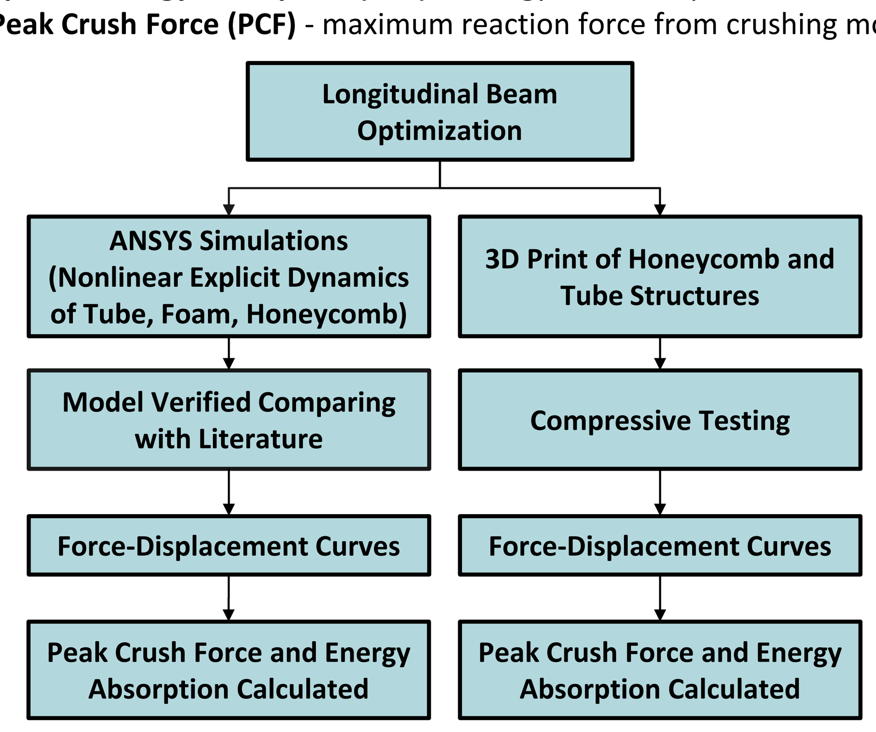


Figure 10. Testing Process Flowchart

RESULTS & TEST DATA

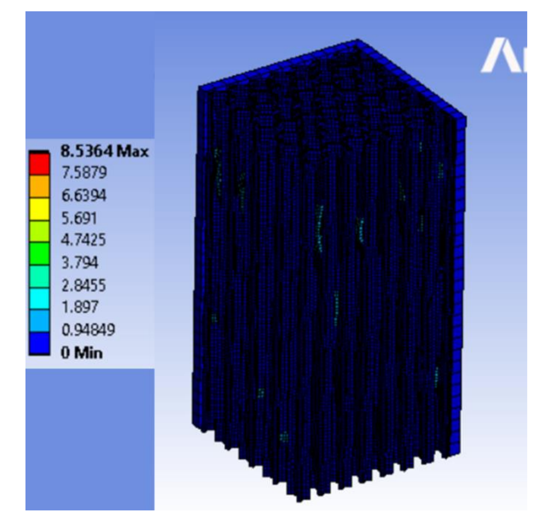


Figure 11. Deformation Before Failure

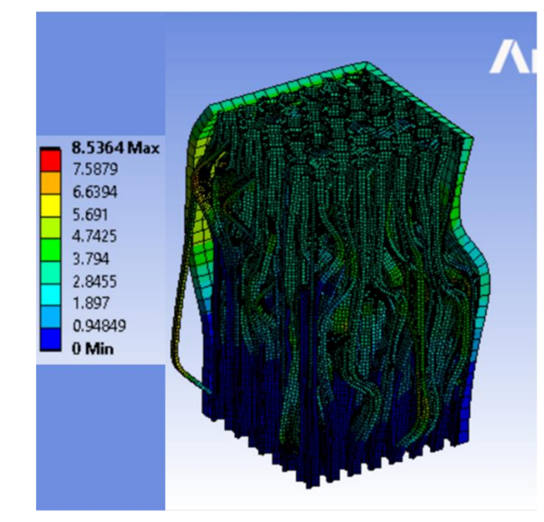


Figure 12. Deformation just after Failure

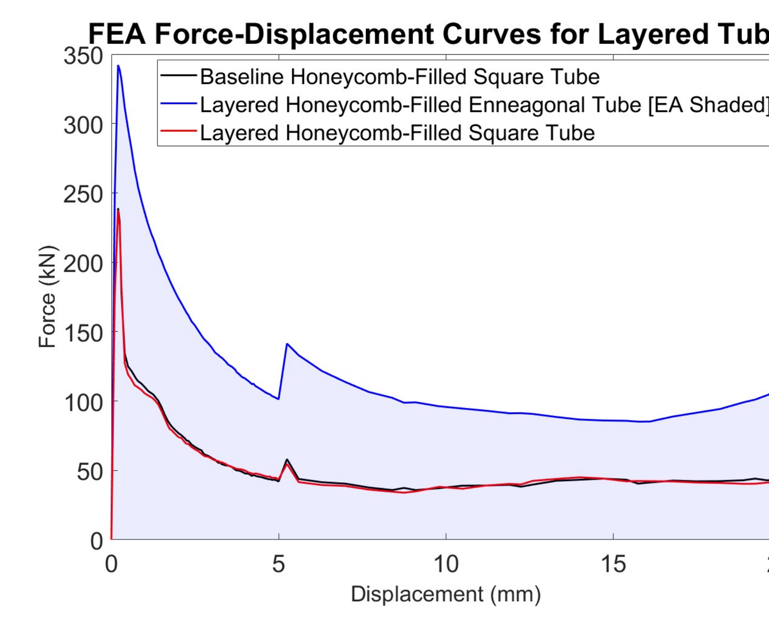


Figure 13. Force-Displacement Curve for Best Layered Tubes. Shading indicates energy absorbed found through the area under the curve

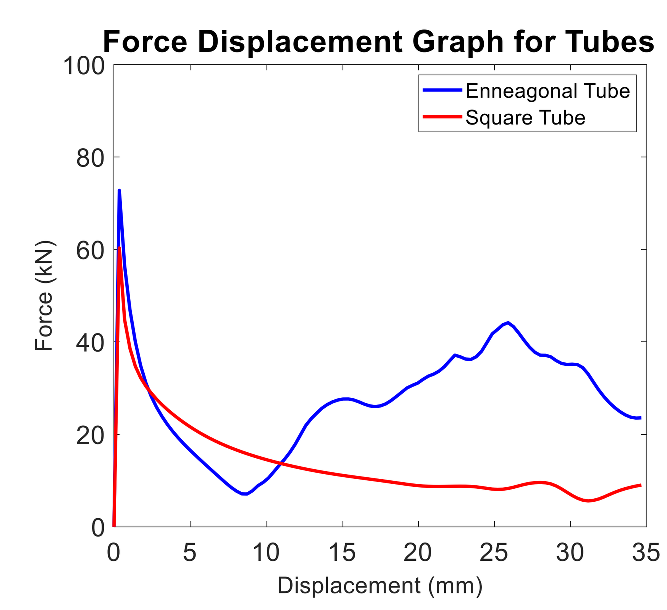


Figure 14. Force-Displacement Curve for Empty Tubes

DISCUSSION

- Both honeycomb-filled and empty enneagonal tubes outperform square tubes in PCF and SEA significantly.
- FEA simulation showed negligible benefit in SEA and PCF in functionally grading honeycomb cell wall thickness or layered designs.

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