Project Description and Technical Deliverables

Revised: 3/15

Project:	Mapping design parameters of foam composites in midsoles
Sponsor:	Adidas
Technical focus:	Mechanical testing and modeling
Class:	2.98 / 2.980: Sports Technology: Engineering & Innovation
Semester:	Spring 2020

PROJECT DESCRIPTION

Foam materials are used in sports equipment to provide cushioning, energy absorption, and protection. In footwear, foam is typically used to provide cushioning, balanced with energy return. Different materials or densities are used to provide differences in mechanical properties -- like bending stiffness or compression -- while balancing the tradeoff in weight and cushioning. One can also introduce stiff plates (such as TPU or Carbon Fiber) at various positions in the foam composite to alter the impact absorption of the structure.

Example: *Two adidas athletes would like to have shoes that provide very different feels on the foot. Athlete 1 would like a very soft initial cushion while walking around but then stiffer while running. Athlete 2 would like to have a stiffer initial feel of the shoe but have the shoe feel softer when running. Adidas would like to use the same materials to build shoes for both athletes with changes in the order of construction.*

The goal of this project is to develop, test, and validate a model that can predict the performance of a layered combination of stiff and soft materials, and be used to quantify the tradeoffs between weight, cushioning, bending stiffness, and energy return (and hence and optimize design). Tasks will include (but are not limited to):

- Mechanical testing of plates to determine material properties in bending and in compression
- Modeling stiffness of individual components and stacked composites of multiple components (in bending and compression); note that your model may need to include a rate-dependent piece
- Applying the model to optimizing various performance metrics while holding others constant (e.g. minimize weight while maintaining key features in the load deformation curve)
- Mechanical testing of plates to validate the model and measure empirical parameters
- Building prototype footwear samples or pads

March 17 notes and revisions: Given that both educational and research efforts are being moved off campus to combat COVID-19, we need to adjust the deliverables for your project to eliminate on-campus testing and adapt to the evolving situation. (In general, it is quite common to adjust our objectives as we acquire more data and information, although this case is extreme!) In order to adapt to the new landscape, it is likely that you will need to reorganize your team. We suggest that you consider the following approach (but we look forward to discussing this with you during our next virtual meeting and hearing your ideas).

User Interface Sub-Team (UIST): Design the user interface and implement the final design in MATLAB.

Inputs (from user)

- Number of layers in the composite
- Thickness of each layer
- Material type (e.g. boost, carbon fiber, etc) of each layer

Output (to user, values obtained from MeST code)

- Effective bending stiffness, B_{eff}
- Effective compression modulus, E_{eff}
- Weight

Mechanics Sub-Team (MeST): Implement the algorithm to calculate effective bending stiffness, B_{eff}, effective compression modulus, E_{eff} and weight of the composite.

Inputs

- Geometry i.e. number and thickness of the layers (from UIST code)
- Constitutive models for materials in each layer (from MaST code)

Output (to UIST code)

- Effective bending stiffness, B_{eff}
- Effective compression modulus, E_{eff}
- Weight

Materials Sub-Team (MaST): Determine constitutive relationships (functional representations of stress-strain curves) for relevant materials.

Inputs (from UIST code)

- Material type

Output (to MeST code)

- Constitutive models

DELIVERABLES

Individual deliverable (due 2/20):

1. Perform a literature review of foam compression and foam-and-plate composite materials. Summarize the key points from this review.
2. For a stacked composite made up of two different linear elastic materials, derive an expression for the effective bending modulus (B) and effective compression modulus (E) of the composite as a function of the modulus of the individual materials (E_1) and (E_2), the number of layers (N), and the thicknesses of layers. Consider two cases:
    a. Material 1 has layer thickness h_1 and material two has layer thickness h_2.

   b. The layer thicknesses are given by ($h_{1,}$ h_2, h_3 ... h_N)
3. Comment on the trends you observe in your model (you may find plots or visualizations helpful here).

*For **this deliverable only**, each member of the team should hand in their own analysis and visualizations (although we encourage you to work closely with your teammates to share ideas, help each other access the data, and discuss the project).*

Progress Report in lieu of Team deliverable 1 (due 4/7):

Measure and determine the constitutive models of the individual components. (MaST). For this deliverable, you may use the data you collected before on-campus operations at MIT shut down.

1. Determine whether the constitutive relationships are linear or nonlinear in the parameter range of interest. You can estimate the parameter regime (e.g., strain) by analyzing the maximum compressive and bending levels of the midsole during exercise.
2. Determine whether the constitutive relationships are rate-dependent in the parameter regime of interest (you may refer to experimental data conducted at varying strain rates).
3. Modify your elastic linear model to incorporate nonlinear (and possibly rate-dependent) effects as necessary.
4. Compare your modified constitutive model to the mechanical measurement for the individual components.

Note that this deliverable is heavily weighted towards the MaST, but UIST and MeST have a lot to do for the next one!

*For this and all following technical deliverables, you should turn in only **one** assignment for the whole team.*

Team deliverable 2 (due 4/21):
For the rest of the semester, we will rely on data that you have already collected (and possibly data that adidas can provide).

UIST: Wireframe the user interface and iterate your design with feedback from adidas. Select a design that you will implement in the next deliverable. Be sure to identify properties that are crucial for the performance of sports shoes (such as bending and compression stiffness, weight; are there properties that we are missing that should be included in your output?) Note that these properties should be quantifiable.

MeST: Based on the constitutive models of the individual components (such as rubber foams and stiff carbon plate), numerically calculate the effective compression and bending stiffness (or moduli) of a stack of materials.

MaST: Implement the code that will pass constitutive models to MeST.

Final engineering report (due 5/12):

Put it all together!

UIST: Implement your user interface design in MATLAB. Be sure to coordinate with MeST and MaST so that you can pass the relevant data between subroutines smoothly. (Do not leave the connections until the last minute! Be sure to think about the interface with the other sub-teams from the beginning of your design).

MeST: Interface your mechanical computation with the user interface team's code.

Everyone: Test your design tool! Use your newly developed framework to map out interesting parameter regimes. Explore how features of your constitutive relationships and geometry relate to properties that are of interest to the user.

Note: this revised roadmap focuses on the "forward problem" i.e. given a stack of materials and the geometry of the stack, calculate the effective properties. The harder problem is the "inverse problem" namely, given desired effective properties, find that stack that produces those properties. If you finish your design tool for the forward problem with some time to spare, let us know and we'll help you to take a swing at the inverse problem. (It's more difficult, but fun!)

RESOURCES

Sponsor Contact:	Keith Kirkwood (Keith.Kirkwood@adidas.com)
Primary Mentor:	Xinyu Mao (maoxy@mit.edu)
IDC Shop Manager:	Chris Haynes (haynesc@mit.edu)