Alice Hong
Individual Deliverable
2.980 Sports Technology
02.20.2020

Adidas: Mapping Design Parameter of Foam Composites in Midsoles

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.

DELIVERABLES

1. Literature Review

Foam Compression

Sports footwear plays great role on preventing from injuries and enhancing the performances of the wearers. The function, cushioning, stability, flexibility, fitting, lightness, air permeability durability and grip are the important factors in the design process of the shoes, which are layered with upper, mid, bottom soles. The materials being used in mid-sole and outer-sole influence the performance as it absorbs and give back the energy corresponding to force. One of the features of foam is the density which sometime referred to as weight. Firmness determines the feel of foam and how it yields to weight and pressure. The mechanical performance testing of compression strength of the soles are called Indentation Load Deflection (ILD). With the various similar materials being used, it is important to set the standardization the evaluation and sample size as thickness and size of a material affects how much the weight can be bear for every foam.

Another way to evaluation is compression modulus, which combines the ratio of compression value to represent support capability.

Foam-and-plate component materials

There are many types of foam used for mid-sole. Generally, it is divided into two types: “Open Cell” and Closed Cell” foam. Open cell foam is generally soft and made from Polyurethane plastic. This type of foam is commonly known as “KF” or “KFF” foam. Reticulated foam is often used for ventilation purpose which allows air and water flow freely. Closed cell foam that is denser than open cell foam is often used for midsoles of shoes. The stretchability, material and size of the cell determines the density of the foam. The most commonly used materials are EVA (ethyl vinyl acetate), PE (Polyethylene), SBR (Styrene butadiene rubber) PU (Polyurethane), Latex, and Neoprene. Nowadays, sports companies are looking into different way to combine the material with additive manufacturing. For example, Adidas uses Carbon that uses the digital light projection, oxygen permeable optics to program liquid resin to achieve high-resolution intricate lattice layers. Traditional methods can’t deliver high-performance monolithic designs and often limited to molding. According to individual physiological data and needs on demand, the foam in the midsole and the carbon fiber plate can be combined to improve runner’s ankles mechanics by stabilizing the joint and preserving the energy. Therefore, design an experiment of effective bending and compression modulus is critical when testing the different version of foams and plates component materials.

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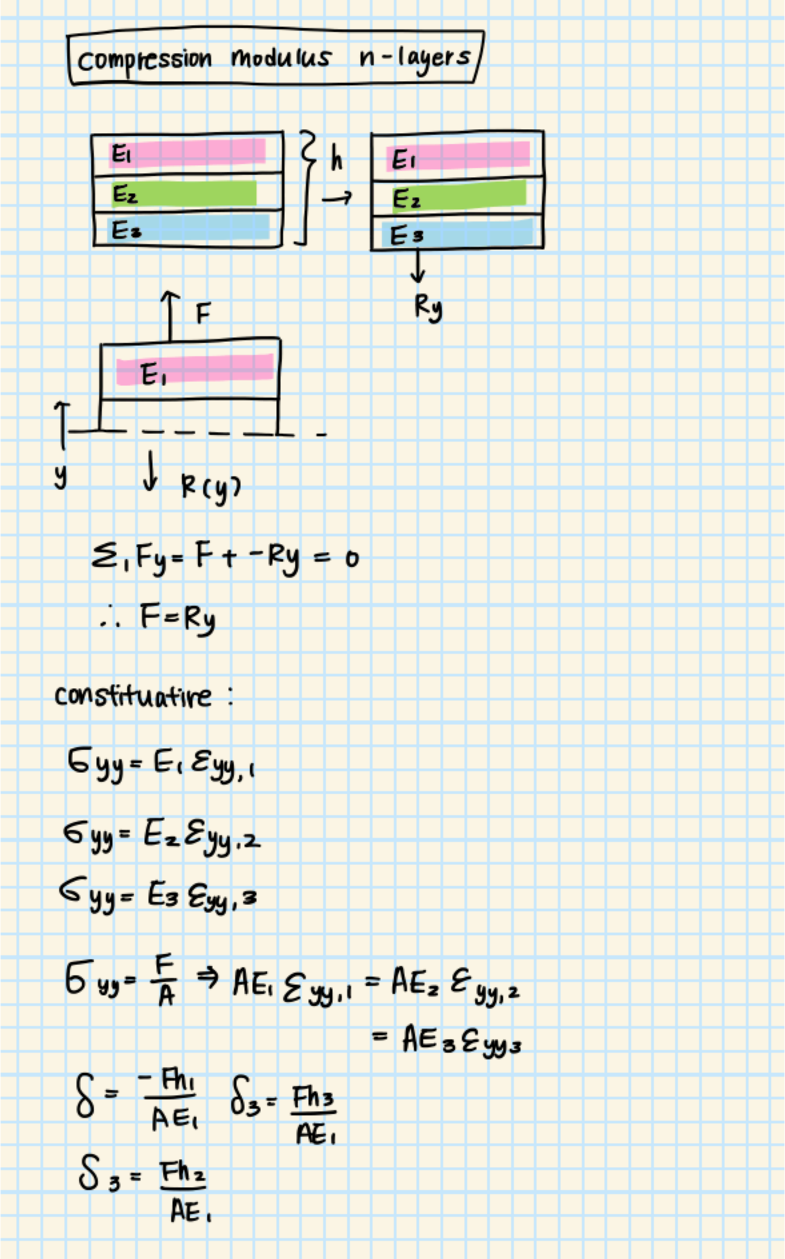
2. Effective Compression Modulus (E)



Compression modulus n-layers

$\Sigma_1 F_y = F + -R_y = 0$

$\therefore F = R_y$

constituative :

$\sigma_{yy} = E_1 \varepsilon_{yy,1}$

$\sigma_{yy} = E_2 \varepsilon_{yy,2}$

$\sigma_{yy} = E_3 \varepsilon_{yy,3}$

$$\sigma_{yy} = \frac{F}{A} \Rightarrow AE_1 \varepsilon_{yy,1} = AE_2 \varepsilon_{yy,2} = AE_3 \varepsilon_{yy3}$$

$\delta = \frac{-Fh_1}{AE_1}$ $\delta_3 = \frac{Fh_3}{AE_1}$

$\delta_3 = \frac{Fh_2}{AE_1}$

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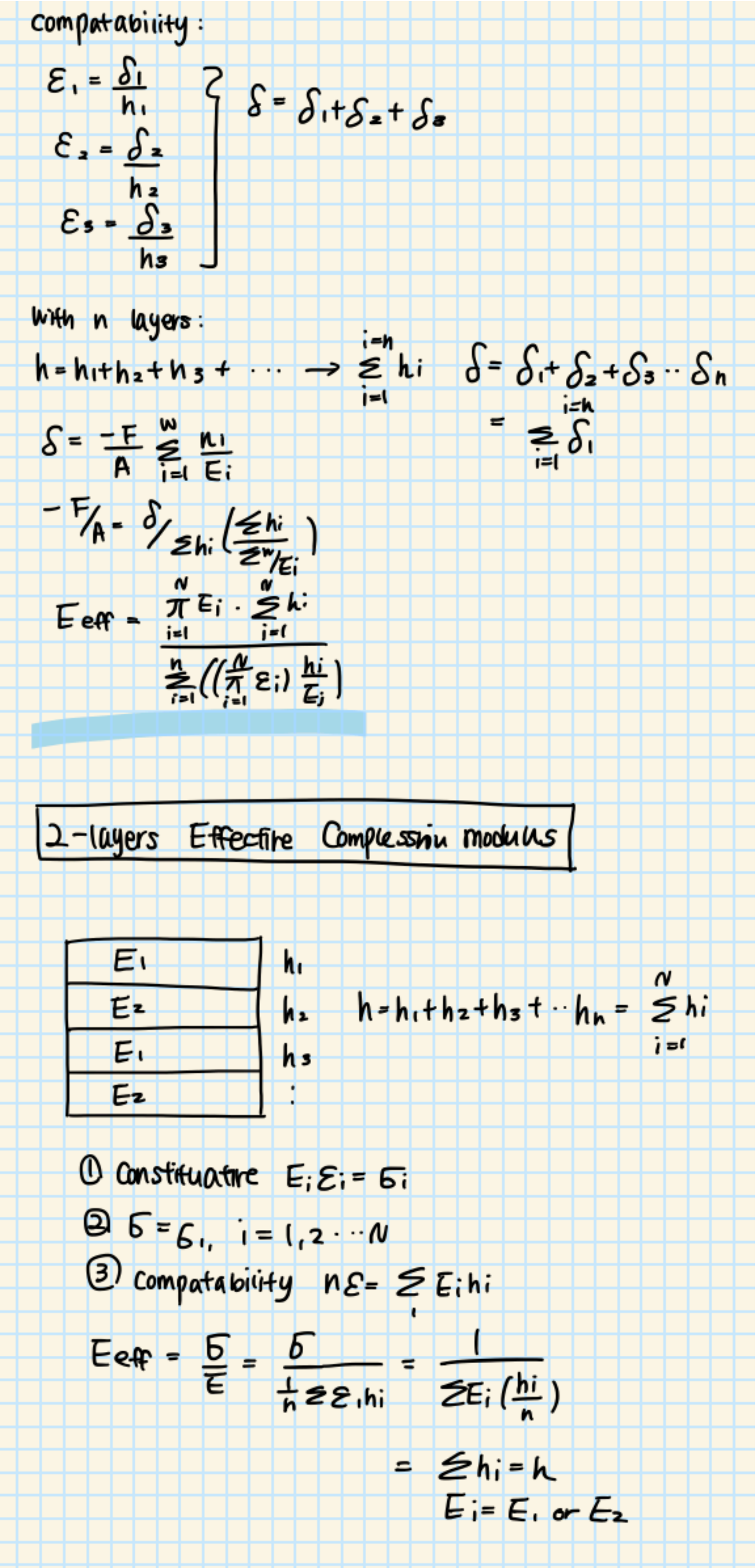

compatability:

$$\left.\begin{aligned}\varepsilon_1 &= \frac{\delta_1}{h_1}\\ \varepsilon_2 &= \frac{\delta_2}{h_2}\\ \varepsilon_3 &= \frac{\delta_3}{h_3}\end{aligned}\right\} \delta = \delta_1 + \delta_2 + \delta_3$$

With n layers:

$$h = h_1 + h_2 + h_3 + \cdots \rightarrow \sum_{i=1}^{i=n} h_i \qquad \delta = \delta_1 + \delta_2 + \delta_3 \cdots \delta_n = \sum_{i=1}^{i=n} \delta_1$$

$$\delta = \frac{-F}{A} \sum_{i=1}^{w} \frac{h_i}{E_i}$$

$$-F/_A = \delta/_{\Sigma h_i} \left(\frac{\Sigma h_i}{\Sigma^{w}/E_i} \right)$$

$$E_{eff} = \frac{\prod_{i=1}^{N} E_i \cdot \sum_{i=1}^{N} h_i}{\sum_{i=1}^{n} \left(\left(\prod_{i=1}^{N} E_i \right) \frac{h_i}{E_j} \right)}$$

2-layers Effective Compression modulus

E1 | h1
E2 | h2
E1 | h3
E2 | :

$$h = h_1 + h_2 + h_3 + \cdots h_n = \sum_{i=1}^{N} h_i$$

① Constituative $E_i \varepsilon_i = \sigma_i$

② $\sigma = \sigma_1, \quad i = 1, 2 \cdots N$

③ compatability $n\varepsilon = \sum_{i} E_i h_i$

$$E_{eff} = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\frac{1}{n} \Sigma \varepsilon_i h_i} = \frac{1}{\Sigma E_i \left(\frac{h_i}{n} \right)}$$

$$= \Sigma h_i = h$$

$$E_i = E_1 \text{ or } E_2$$

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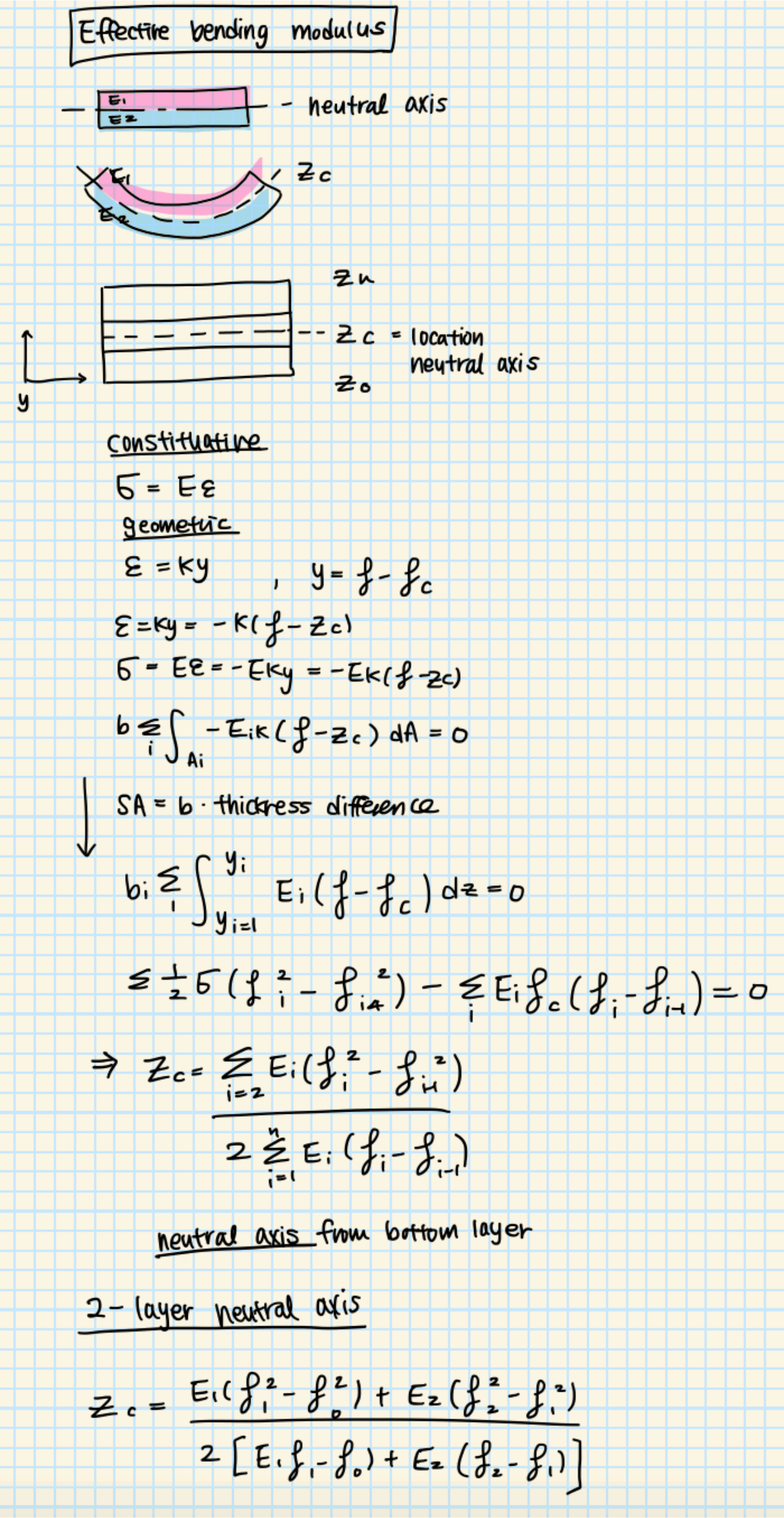
Effective Bending Modulus (B)



Effective bending modulus

Constituative

$\sigma = E\varepsilon$

geometric

$\varepsilon = ky \quad , \quad y = z - z_c$

$\varepsilon = ky = -k(z - z_c)$

$\sigma = E\varepsilon = -Eky = -Ek(z - z_c)$

$b \sum_i \int_{A_i} -E_i k(z - z_c)\, dA = 0$

$\downarrow$ $SA = b \cdot$ thickress difference

$b_i \sum_i \int_{y_{i=1}}^{y_i} E_i (z - z_c)\, dz = 0$

$\sum \frac{1}{2} \sigma (z_i^2 - z_{i4}^2) - \sum_i E_i z_c (z_i - z_{i-1}) = 0$

$$\Rightarrow z_c = \frac{\sum_{i=2} E_i (z_i^2 - z_{i-1}^2)}{2 \sum_{i=1}^{n} E_i (z_i - z_{i-1})}$$

neutral axis from bottom layer

2- layer neutral axis

$$z_c = \frac{E_1(z_1^2 - z_0^2) + E_2(z_2^2 - z_1^2)}{2\left[E_1 z_1 - z_0) + E_2(z_2 - z_1)\right]}$$

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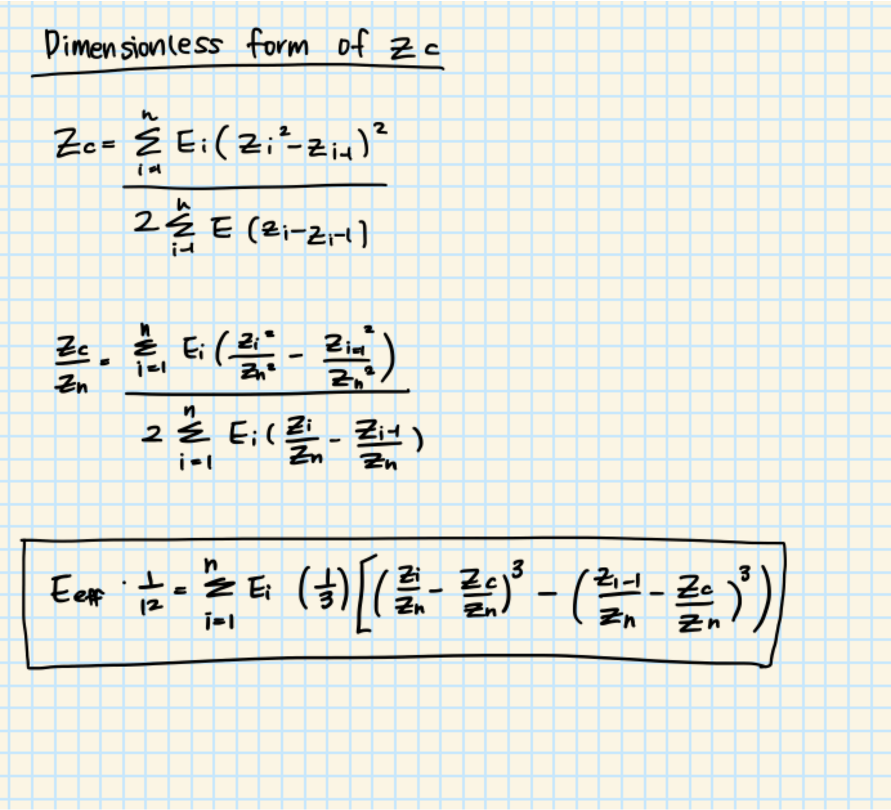

Dimensionless form of Z_c

$$Z_c = \frac{\sum_{i=1}^{n} E_i (z_i^2 - z_{i-1})^2}{2 \sum_{i=1}^{n} E (z_i - z_{i-1})}$$

$$\frac{Z_c}{Z_n} = \frac{\sum_{i=1}^{n} E_i \left(\frac{z_i^2}{Z_n^2} - \frac{z_{i-1}^2}{Z_n^2} \right)}{2 \sum_{i=1}^{n} E_i \left(\frac{z_i}{Z_n} - \frac{z_{i-1}}{Z_n} \right)}$$

$$\boxed{E_{eff} \cdot \frac{1}{12} = \sum_{i=1}^{n} E_i \left(\frac{1}{3}\right) \Bigg[\left(\frac{z_i}{Z_n} - \frac{Z_c}{Z_n} \right)^3 - \left(\frac{z_{i-1}}{Z_n} - \frac{Z_c}{Z_n} \right)^3 \Bigg)}$$

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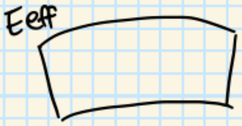
Balance of moment

σ = stress

$$\int_{A_i} \sigma y A = \sum_i \int_{A_i} \sigma (z - z_c)\, \overset{dA}{d(b(z - z_c))} + M = 0$$



one beam w material E_{eff}

$$dA = d[b\underbrace{(z - z_c)}_{y}]$$

$$\sum_i \int -E \cdot K(z - Z_c) \cdot (z - z_c)\, d(b(z - z_c))$$

$$= \underbrace{-E_{eff} K}_{\text{stress}} \underbrace{yy}_{\text{distance}}\, d \underbrace{[by]}_{\text{area}} + M = 0$$

$$\frac{1}{3} E_i K (z - z_c)^3 \Big|_{z_{i-1}}^{z_1} b + M = 0$$

$$b \sum_{i=1}^{n} \frac{1}{3} E_i \underbrace{(z - z_c)^3}_{\text{geometric constant}} \Big|_{z_{i-1}}^{z} = b \cdot E_{eff} \cdot \frac{1}{3} y^3 \Big|_{-h/2}^{h/2}$$

$$= E_{eff} \cdot \frac{1}{3} \cdot \frac{h^3}{8} \cdot 2$$

$$\sum E_i \frac{1}{3} \left[(z - z_2)^3 - (z_{i-1} - z_c)^3 \right]$$

$$= E_{eff} \cdot \frac{1}{3} \cdot \frac{h^3}{8} \cdot 2 = E_{eff} \cdot \frac{1}{12} h^3$$

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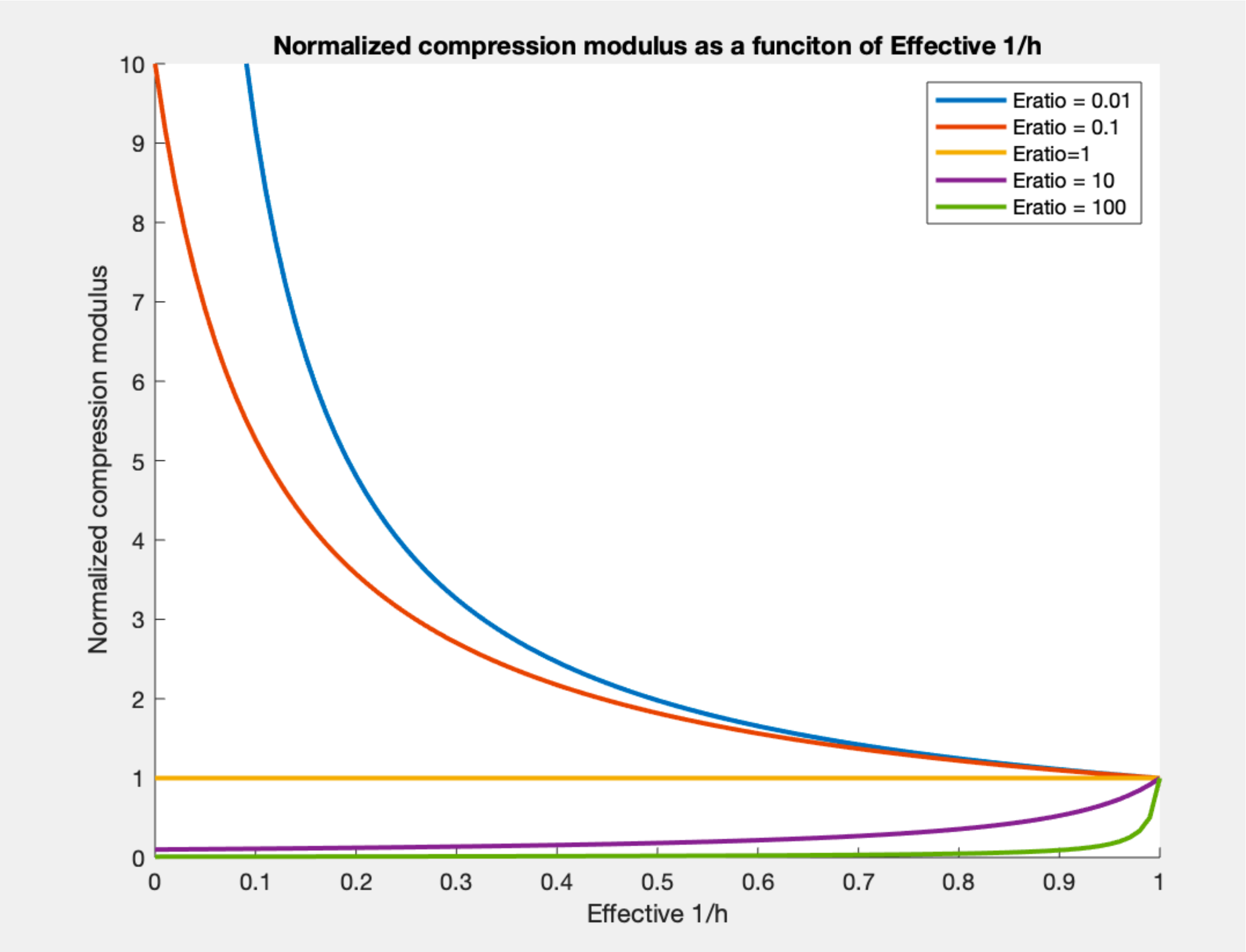
3. Effective Modulus Plot Analysis



Analysis of the Normalized Compression Modulus

As there is no sample data on the compression of materials, we used the dimensionless equation with experimental values. The E ratio shows how the height ratio between layers affects the normalized compression modulus. As the ratio of the height of E1 to the total of height of all layers increases, the normalized compression modulus decreases exponentially. As the ratio of E1/E2 decreases, the height of E1 affects the compression modulus.

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Matlab Code

```
clc
clear
close all

% This script is for the calculation of effective compression modulus B
(dimensionless)

% Step 1: defination of variables
h1_eff = 0:0.01:1;                                      % overall thickness
of material 1
h1_eff = h1_eff';
[row, column] = size(h1_eff);
h2_eff = ones([row, column]) - h1_eff;                  % overall thickness
of material 2

E_ratio = [0.01; 0.1; 1; 10; 100];                      % modulus ratio of
materials 1/2
B_bar = zeros(row, length(E_ratio));

% Step 2: calculation of effective compression modulus B
for i = 1:5                                             % index for E_ratio

    B_bar(:,i) = 1./(h1_eff + E_ratio(i)*h2_eff);       % dimensionless
effective compression modulus B
    E_eff = (1/3)*(()-()
end

% Step 3: plot results
% Plot the influence of h1_eff on B_bar
figure(1)
for i = 1:5
    plot(h1_eff, B_bar(:,i), 'LineWidth',1);
    hold on

end
hold off

% Figure setup
xlim([0,1]);
ylim([0,10]);
xlabel('Effective h_{1} / h','FontSize',11);
ylabel('Normalized compression modulus B / E_{1}','FontSize',11);
legend({'E_{ratio} = 0.01','E_{ratio} = 0.1','E_{ratio} = 1','E_{ratio} =
10','E_{ratio} = 100'},'FontSize',11);

for i = 1:5
    plot(h1_eff, E_bar(:,i), 'LineWidth',1);
    hold on
end
hold off
xlim([0,1]);
ylim([0,10]);
```

```
xlabel('Effective h_{1} / h','FontSize',11);
ylabel('Normalized compression modulus B / E_{1}','FontSize',11);
legend({'E_{ratio} = 0.01','E_{ratio} = 0.1','E_{ratio} = 1','E_{ratio} =
10','E_{ratio} = 100'},'FontSize',11);
```

References

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