Method for Determination of Fabric Density and Fabric Thickness

This document describes how the fabric density and thickness values were determined for use in the shear stress calculations.

Calculation of fabric density is based on the density of fiberglass and polypropylene for the fabrics used in the benchmark study. Assuming no voids, the density values for all three fabrics are the same because they are composed of equivalent volume fractions of the same materials. The following equations are based on a rule-of-mixtures approach assuming a solid material (i.e. no voids).

Definitions of variables used:

\[ v = \text{Volume} \]
\[ v_f = \text{Volume Fraction} \]
\[ m = \text{Mass} \]
\[ d = \text{Density} \]

Mass:

\[ m_{\text{fabric}} = v_{\text{pp}} d_{\text{pp}} + v_{\text{glass}} d_{\text{glass}} \]

Volume:

\[ v_{\text{pp}} = v_{\text{fabric}} v_{f_{\text{pp}}} \]
\[ v_{\text{glass}} = v_{\text{fabric}} v_{f_{\text{glass}}} \]

Density:

\[ d_{\text{fabric}} = \frac{m_{\text{fabric}}}{v_{\text{fabric}}} = \left( v_{\text{fabric}} v_{f_{\text{pp}}} d_{\text{pp}} \right) + \left( v_{\text{fabric}} v_{f_{\text{glass}}} d_{\text{glass}} \right) \]

\[ d_{\text{fabric}} = v_{f_{\text{pp}}} d_{\text{pp}} + v_{f_{\text{glass}}} d_{\text{glass}} \]
The values for density and volume fraction were obtained from: 
http://gtwebsolutions.com/nwbenchmark/load03/materialspecs.pdf

\[ d_{\text{pp}} := 0.91 \times 10^3 \frac{\text{kg}}{\text{m}^3} \quad d_{\text{glass}} := 2.62 \times 10^3 \frac{\text{kg}}{\text{m}^3} \]

\[ v_{f_{\text{glass}}} := 0.342 \quad v_{f_{\text{pp}}} := 1 - v_{f_{\text{glass}}} \]

\[ d_{\text{fabric}} := v_{f_{\text{pp}}} \cdot d_{\text{pp}} + v_{f_{\text{glass}}} \cdot d_{\text{glass}} \]

\[ d_{\text{fabric}} = 1.4948 \times 10^3 \frac{\text{kg}}{\text{m}^3} \quad \text{Final Answer!} \]

The fabric density can be used to calculate the effective fabric thickness assuming no voids. This effective thickness should be equal to the thickness of an equivalent preconsolidated material and it will be used to calculate the cross-sectional area of the sample for the shear stress calculations in the spreadsheets containing the sample data. It makes sense to neglect voids in these calculations because we assume that only the fibers are carrying the load.

As stated, the fabric density values for all three benchmark fabrics are equal. However, the effective fabric thicknesses will not be equal because the fabric area densities are not equal. Below, you will find the calculations for the effective thickness of each of the three benchmark fabrics.

Note that the final answer for the thickness of each of the fabrics is less than the fabric thickness posted on: http://www.mech.northwestern.edu/ampl/benchmark/fabric.htm as expected because the material was assumed to have no voids. Also, the calculated effective thickness for each fabric is approximately equal to the plate thickness posted on: http://gtwebsolutions.com/nwbenchmark/load03/materialspecs.pdf. This result makes sense because a preconsolidated plate should not have voids. As the values posted on the website are round numbers, it is suggested that the posted values be used in the calculations where a material thickness is required. Note that the posted thickness values for the plates were also used where a material thickness was required in stress calculations and moduli calculations in the standardized material properties files for the numerical modeling aspect of the benchmark study.

Definition of variables used:

\[ FAD = \text{Fabric Area Density} \quad t = \text{fabric thickness} \]
User inputs - balanced plain-weave (fabric #3):

\[
FAD := \frac{0.743}{m^2} \quad \text{The value for fabric area density was obtained from:} \\
\text{http://www.mech.northwestern.edu/ampl/benchmark/fabric.htm}
\]

\[
t := \frac{FAD}{d_{\text{fabric}}} \quad t = 4.97 \times 10^{-4} \text{ m} \quad \text{Final Calculated Answer!}
\]

On the forum website the plate thickness for fabric 3 is listed as \( t=0.0005 \text{ m} \).

User inputs - balanced twill weave (fabric #2):

\[
FAD := \frac{1.485}{m^2} \quad \text{The value for fabric area density was obtained from:} \\
\text{http://www.mech.northwestern.edu/ampl/benchmark/fabric.htm}
\]

\[
t := \frac{FAD}{d_{\text{fabric}}} \quad t = 9.934 \times 10^{-4} \text{ m} \quad \text{Final Calculated Answer!}
\]

On the forum website the plate thickness for fabric 2 is listed as \( t=0.001 \text{ m} \).

User inputs - unbalanced twill weave (fabric #1):

\[
FAD := \frac{1.816}{m^2} \quad \text{The value for fabric area density was obtained from:} \\
\text{http://www.mech.northwestern.edu/ampl/benchmark/fabric.htm}
\]

\[
t := \frac{FAD}{d_{\text{fabric}}} \quad t = 1.215 \times 10^{-3} \text{ m} \quad \text{Final Calculated Answer!}
\]

On the forum website the plate thickness for fabric 3 is listed as \( t=0.0013 \text{ m} \).