# New Cushion Curve Method

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# Change

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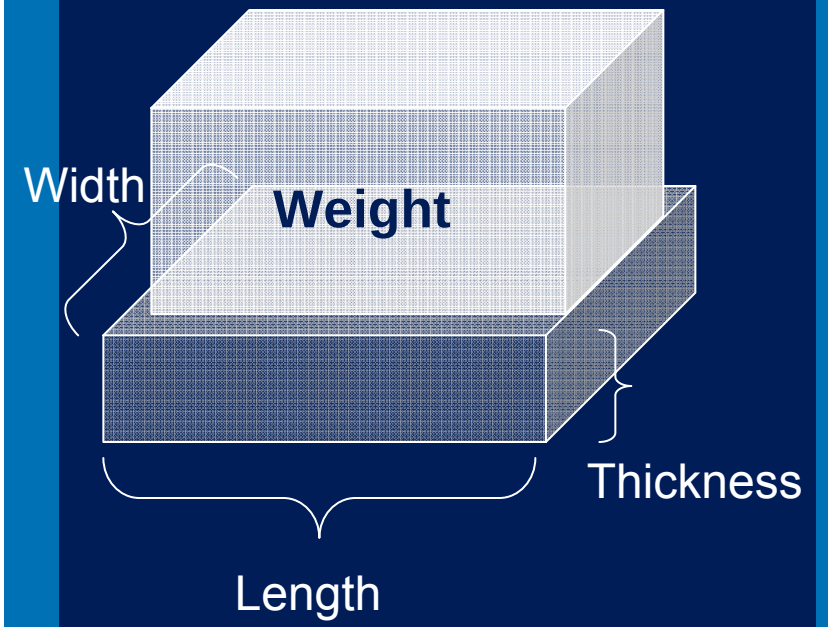
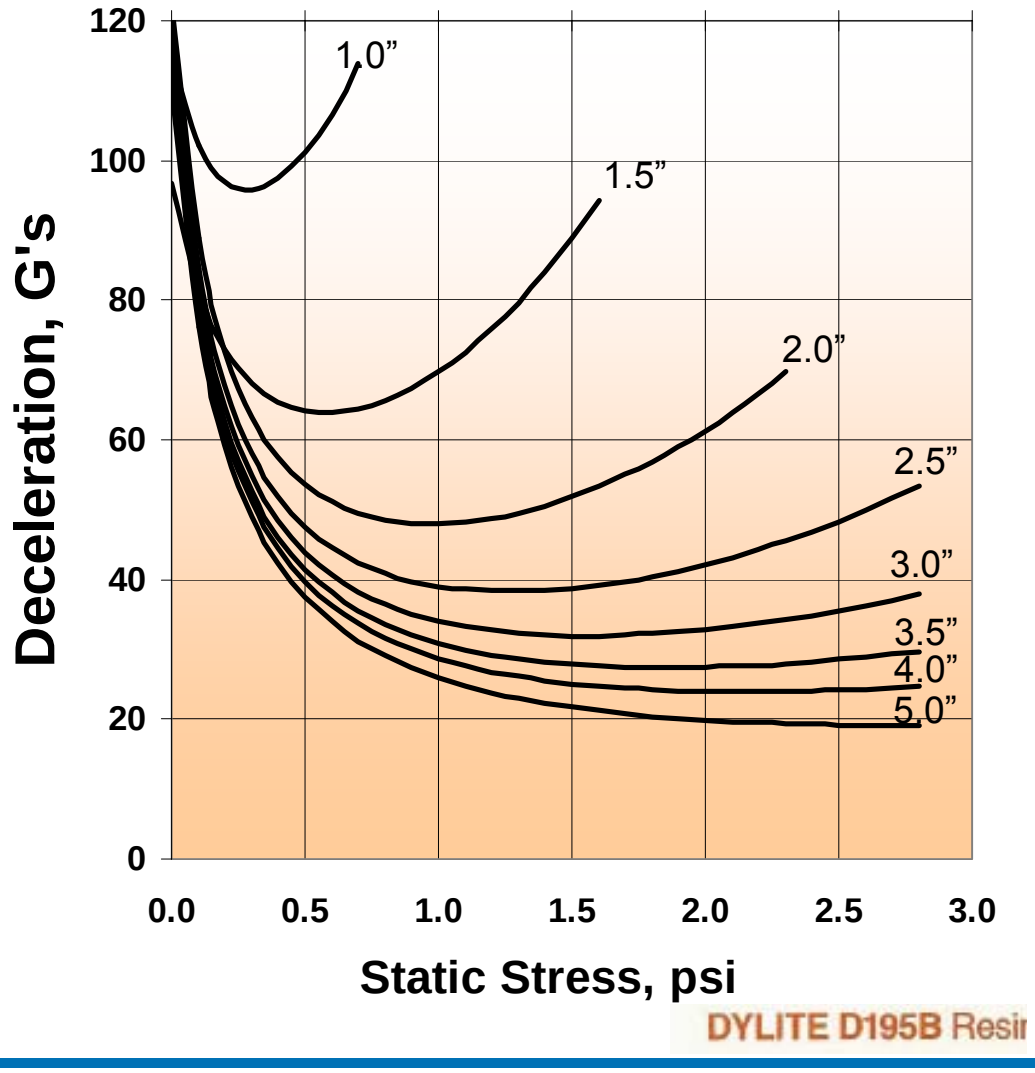
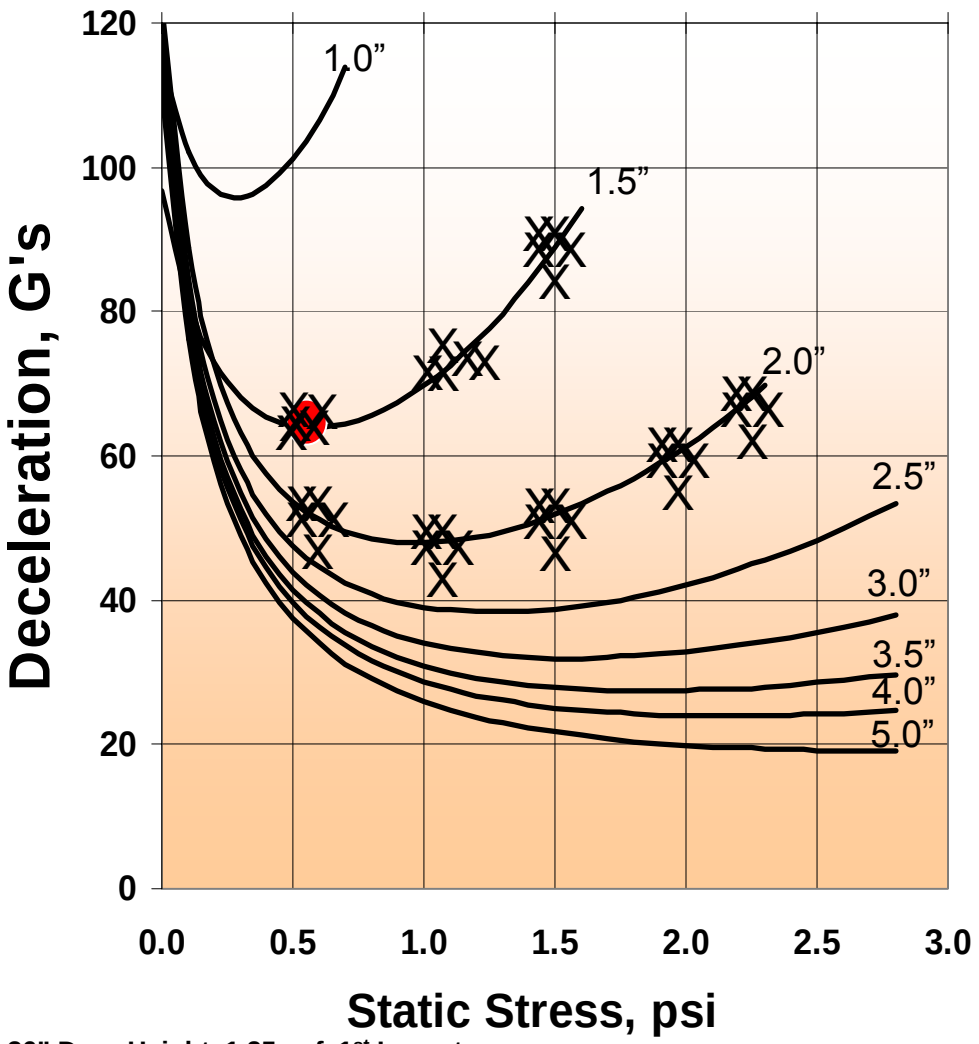
# Change for the Beloved Cushion Curve?

# Current Method: Cushion Curve

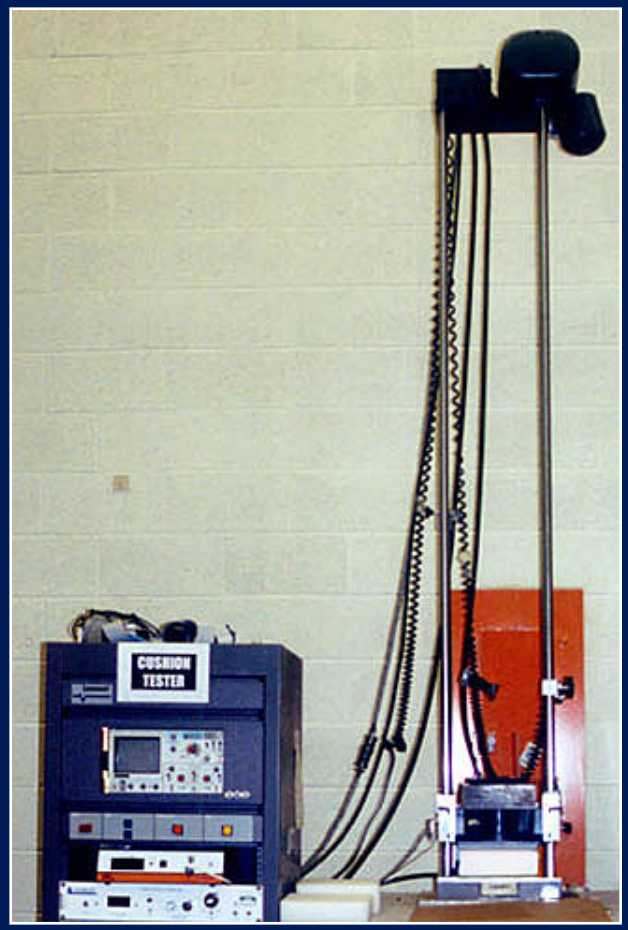


# Limitations of Current Method



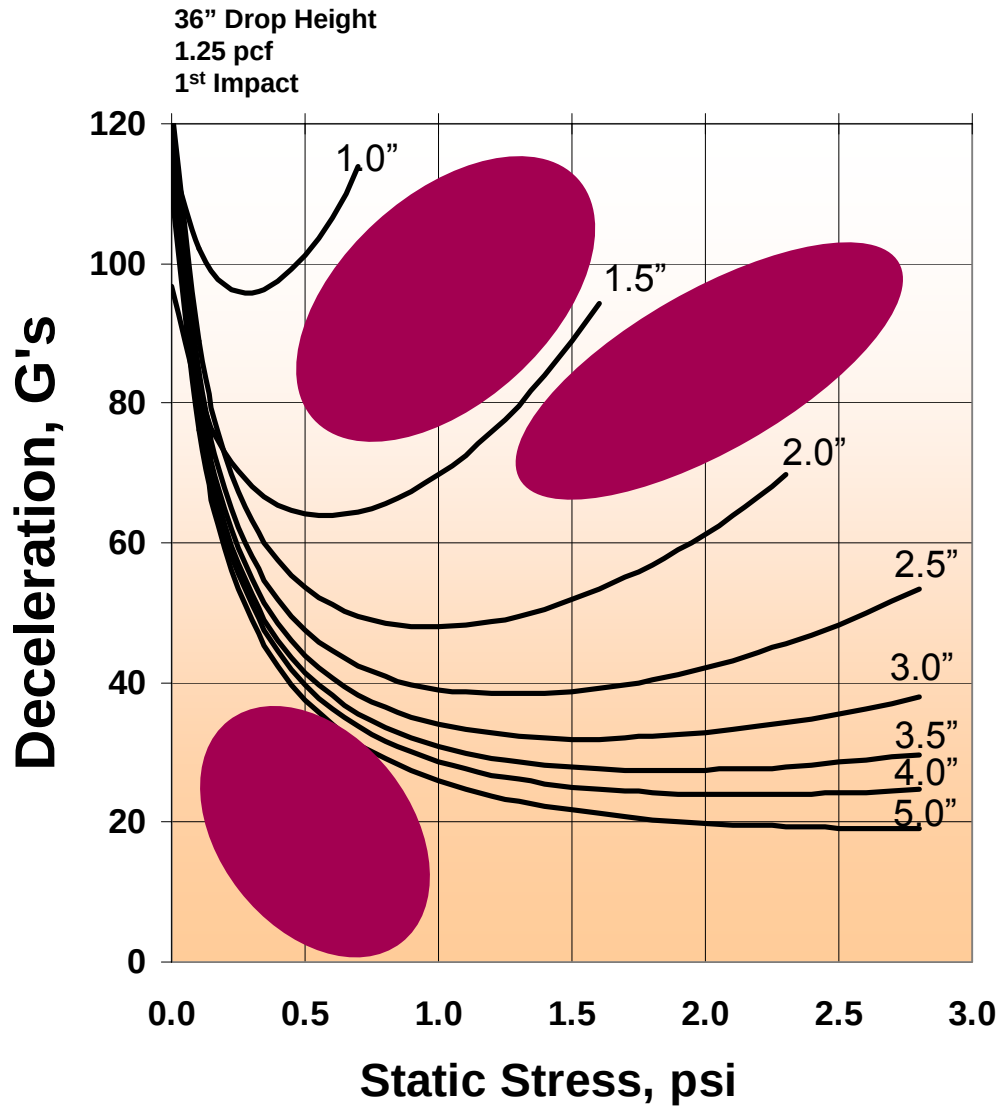

36” Drop Height, 1.25 pcf, 1st Impact




1. <u>Resource-intensive:</u>

ASTM D1596 requires lots of samples and time

# Limitations of Cushion Curves




**2. Limited Data**

What if I want to know G level in these areas?

# Limitations of Current Method

- **Lots of samples: ~10,500 for one curve set**
- **Lots of time: ~175 hours test time, plus sample making and data analysis**
- **Very specific: if you didn't test it, you don't have the curve…**

# Something New

# Something New

**What if you could…**

- Generate a cushion curve for ANY combination of variables?
- Have all the data for these curves represented in ONE easy equation?
- Have all this quickly, at a fraction of the effort of the current method?

# New Method: Stress vs. Energy

- Called “Stress-Energy” method
  - Technically, Dynamic stress vs. dynamic energy density
  - Pioneered by Dr. Burgess @ MSU 1990
- Stress-Energy is about material properties
  - Relationship b/w variables SL, h, t, and G
  - From ONE equation, can construct ANY cushion curve – infinite data from one test!
  - Can be generated with as few as 10 drops

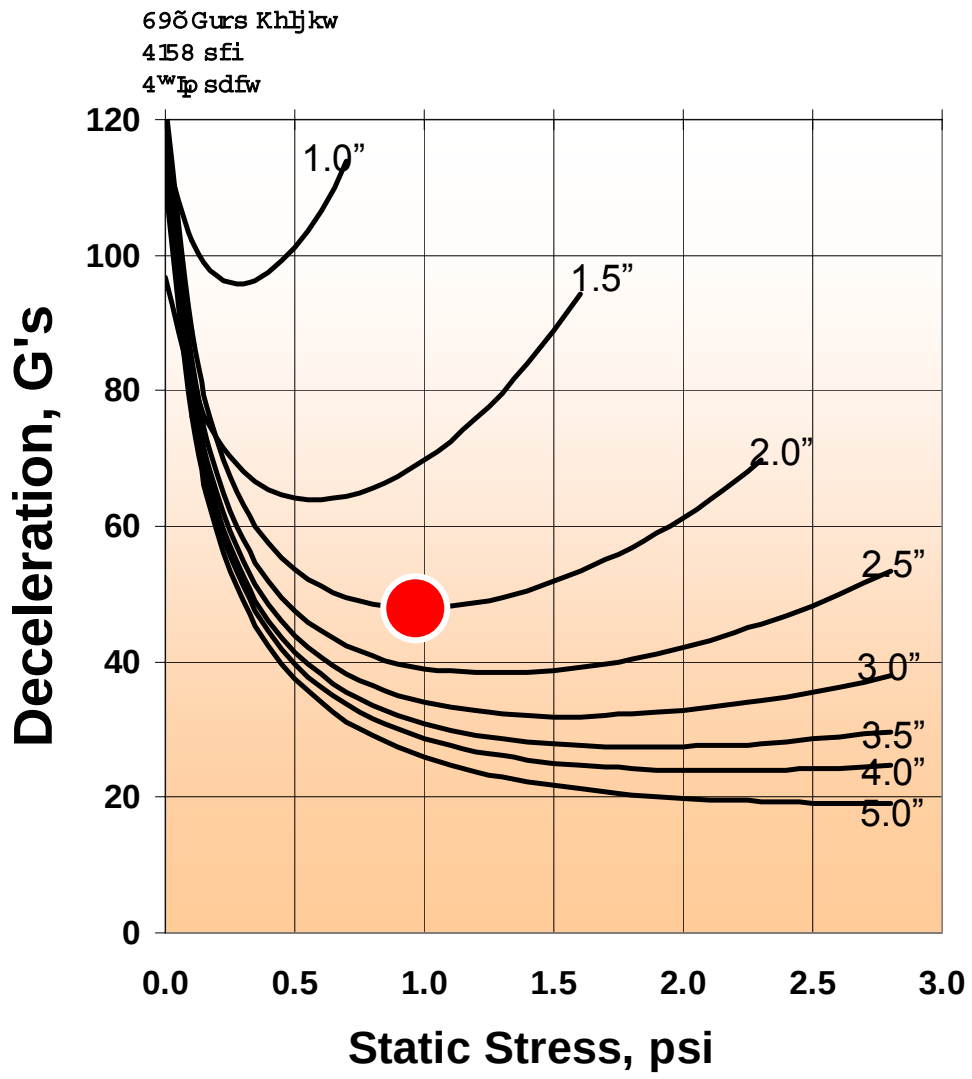
# New Method: Stress vs. Energy

- Simply, the relationship between
  "how much energy the material absorbs" and
  "how the material reacts to shock"

- Dynamic Energy: $\frac{Static\ Loading \times drop\ height}{cushion\ \ thickness}$ or, $\frac{sh}{t}$

- Dynamic Stress: $Peak\ G \times static\ loading$ or, $Gs$

# New Method: Stress vs. Energy




Relationship between existing variables

s = 1.0

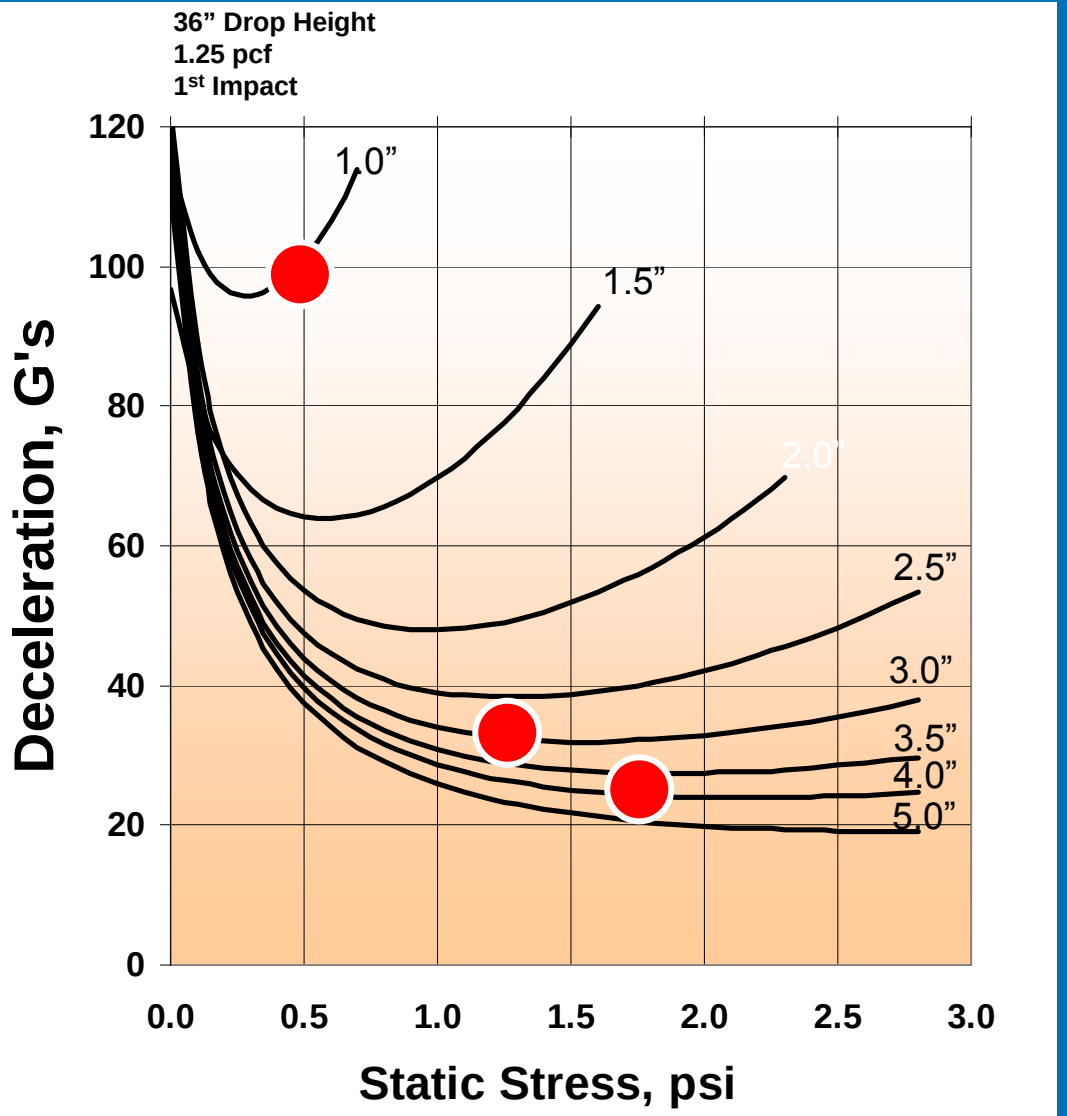
h = 36”

t = 2.0”

Energy = sh/t = 18

Stress = G*s = 50

# New Method: Stress vs. Energy




Does it work?
Test: predict G's

Energy = 18:

| h | s | t | G*s | G |
|---|---|---|---|---|
| 36 | 0.5 | 1.0 | 96 | 95 |
| 36 | 1.5 | 3.0 | 29 | 30 |
| 36 | 2.0 | 4.0 | 22 | 22 |

# New Method: Stress vs. Energy

- One equation describing cushion behavior:

$$y = a e^{bx}$$

- ANY cushion curve can be calculated
  - Closed cell foam, and corrugated
  - See literature from Burgess, Wenger, etc.

# New Method: Stress vs. Energy

$$y = a e^{bx}$$

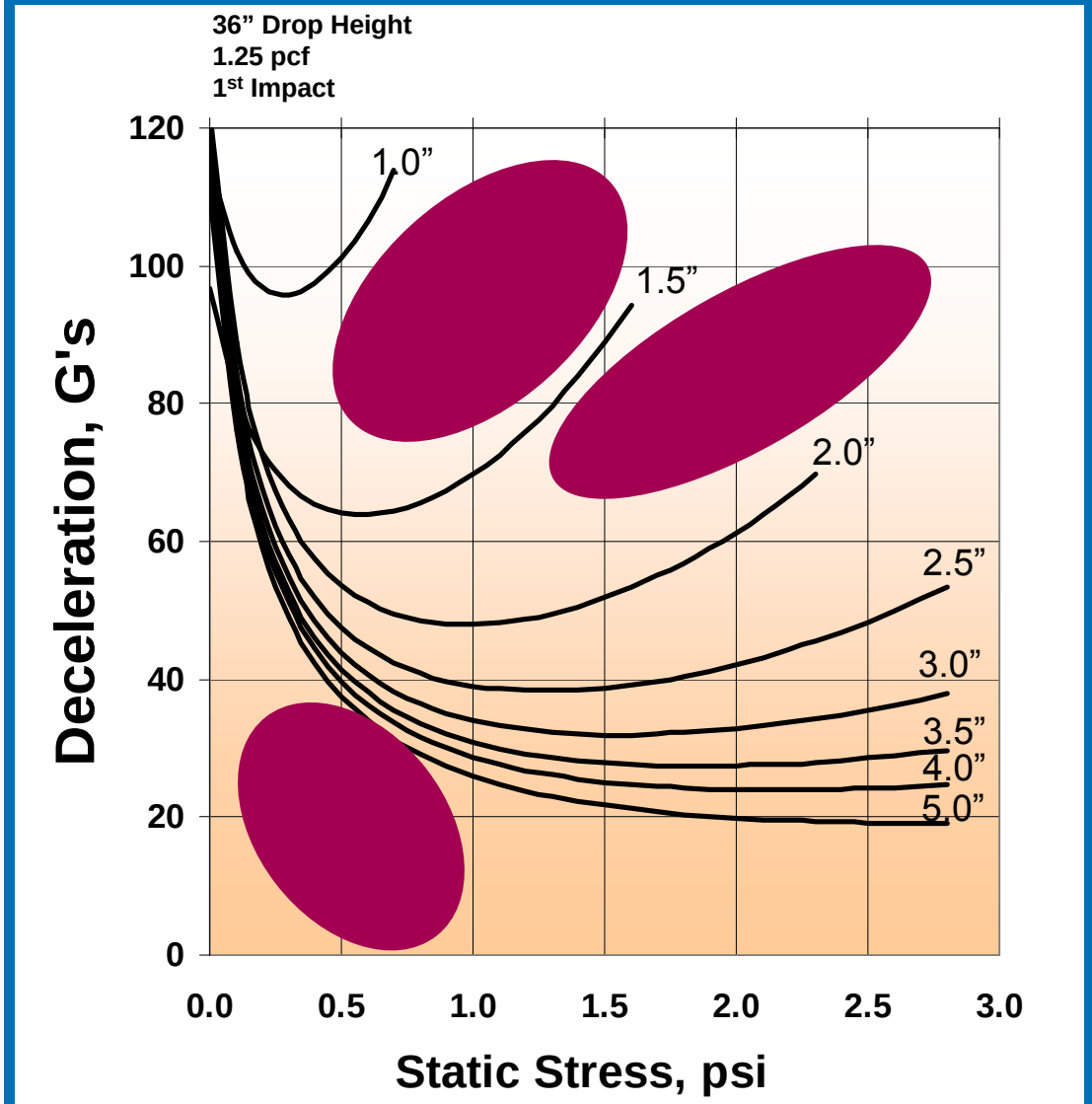
$x$ and $y$ from testing

$y = stress = Gs$

$x = energy = sh/t$

$a$ and $b$ calculated from curve fitting for each specific material and density

# New Method: Stress vs. Energy




**Limited Data**

Don't think of cushion curves as lines on a grid

**Unlimited Data**

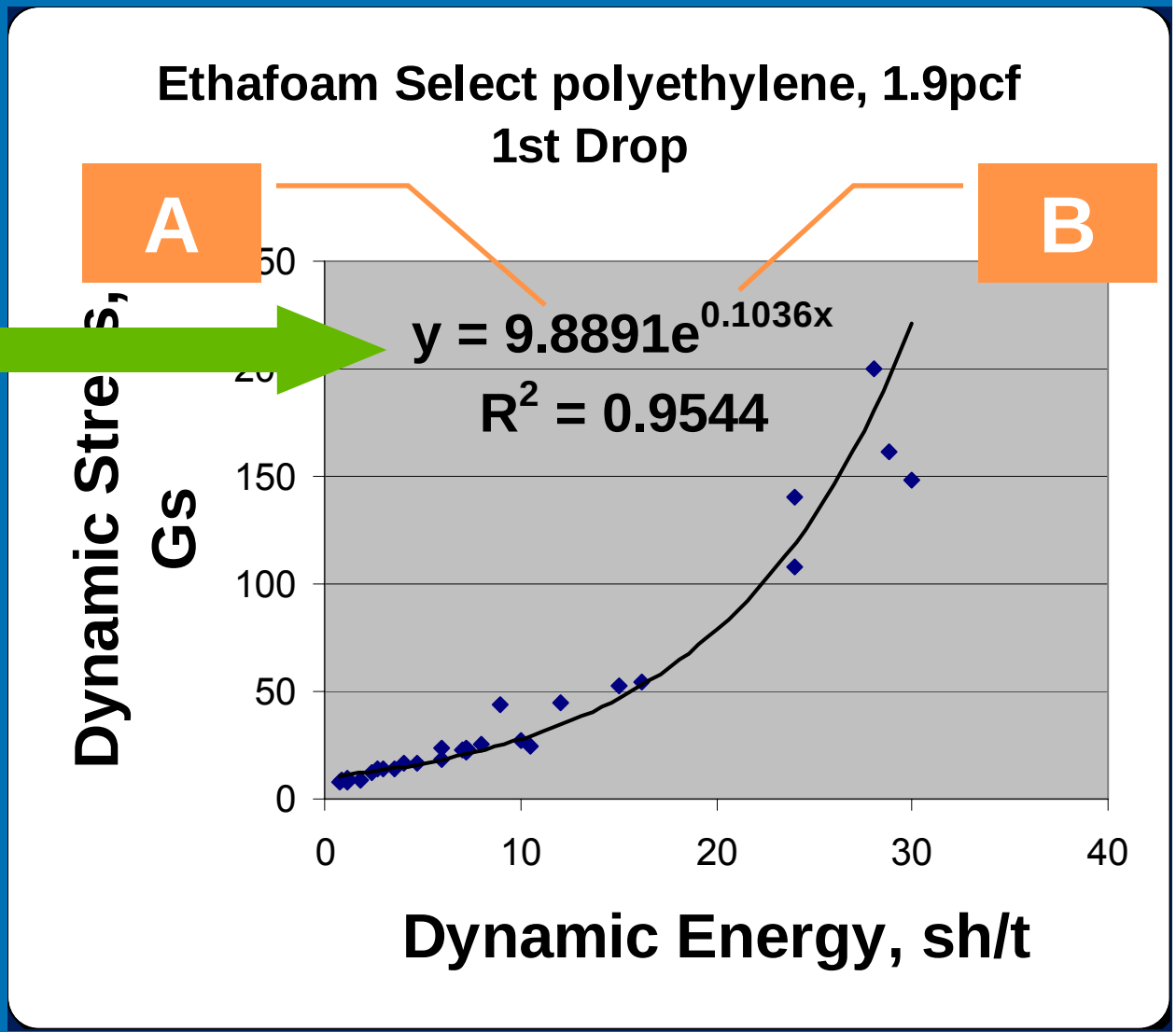
Think of cushion curves as lines from an equation

# New Method: Stress vs. Energy

1. Plot Stress vs Energy

2. LSM, or Power Trendline in Excel

This equation can now be used to draw any cushion curve



# Compare Methods

| | Current: ASTM D1596 | New: Stress vs. Energy |
|---|---|---|
| Test Apparatus | Cushion drop test | Same |
| Collect data | height, area, thickness, G, wt | Same data, less drops |
| Plot results | Plot G vs static stress | Plot Gs vs sh/t |
| Calculate | n/a | Curve fit |

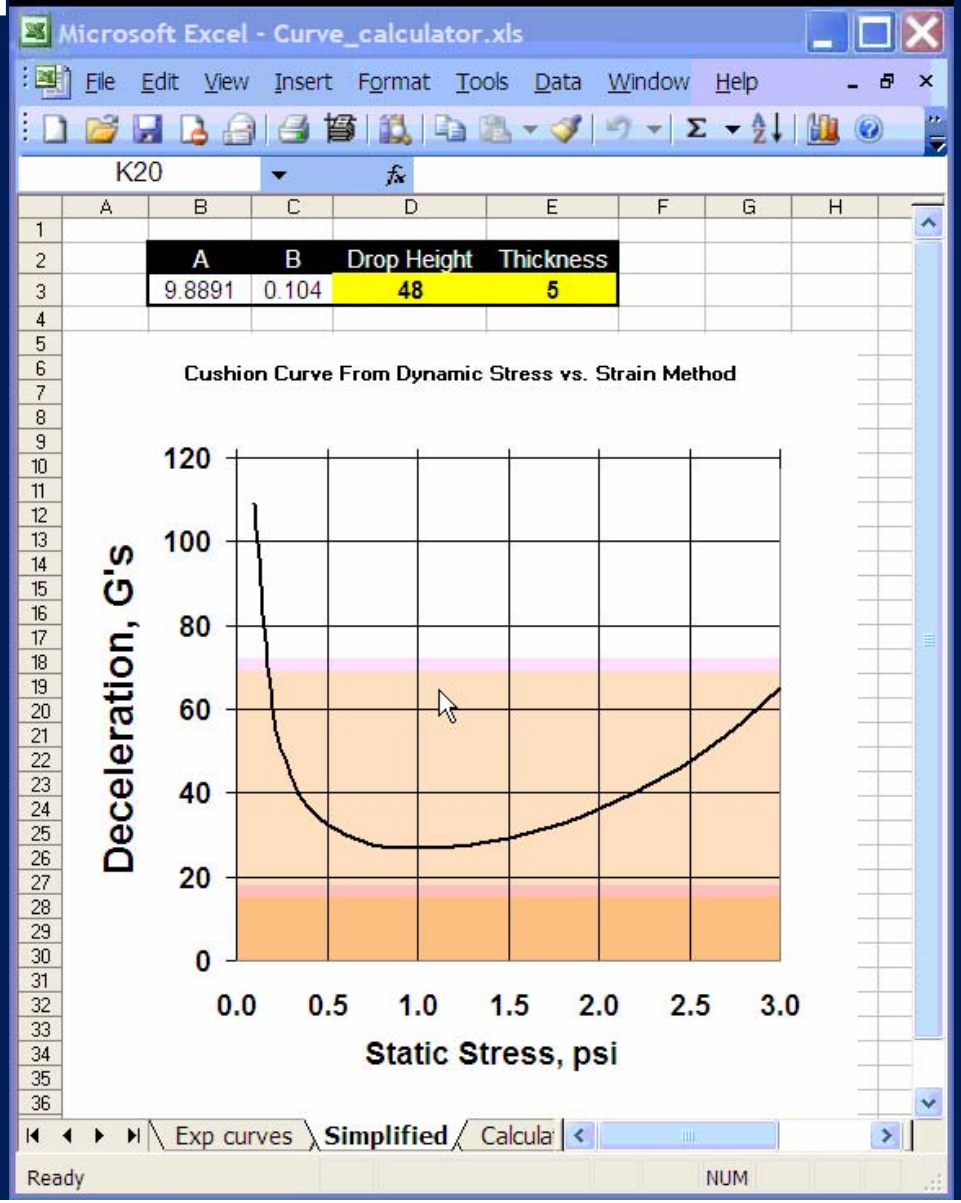
# Compare Methods

| h | w | a | t | G | Gs | sh/t |
|---|---|---|---|---|---|---|
| 18 | 25.6 | 64 | 3.0 | 30 | 12.0 | 2.4 |
| 24 | 32.0 | 64 | 1.5 | 51 | 25.5 | 8.0 |
| 30 | 32.0 | 64 | 1.5 | 55 | 27.5 | 10.0 |
| 36 | 57.6 | 64 | 2.0 | 60 | 54 | 16.2 |
| 42 | 32.0 | 64 | 3.0 | 45 | 22.5 | 7.0 |

**Data Collection is same**

**Calculate and plot new relationships**

# From Equation to Cushion Curve



# Case Study

# Case Study: Background

**LaserJet**

User of Arcel 730

Where are the cushion curves?

NOVA Chemicals®

Arcel 730

Generate Cushion Curves?

**Michigan State**

Stress Energy Method

Develop Test Procedure

**Clemson**

Performed Test

Collect Data

# Case Study: Test Objectives

- Find Stress vs. Energy equation for Arcel 730
  - 1.2 pcf
  - 1.7 pcf
  - 2.2 pcf
  - 3.0 pcf

# Case Study: Test Procedure

**TEST PROCEDURE**

Step 1 Set maximum and minimum limits on the energy absorbed. Since energy = sh/t, the minimum energy corresponds to the smallest s, the smallest h, and the largest t that you want data for. If the intent is to eventually produce a standard set of cushion curves, then for closed-cell foams, these values are usually s = 0.5 psi, h = 12 inches, and t = 6 inches. These give sh/t = 1 in-lb/in$^3$. For open-cell foams, this limit will be lower because the material is not as stiff.

The maximum energy corresponds to the largest s, the largest h, and the smallest t that you want data for. If the intent is to eventually produce a standard set of cushion curves, then for closed-cell foams, these values are usually s = 3 psi, h = 48 inches and t = 3 inches. These give sh/t = 48 in-lb/in$^3$. For open-cell foams, this limit will be lower.

It is not necessary to set an exact range. This step is merely a guideline to establish limits within which to conduct drop tests. Machine limitations may require modifications to this range.

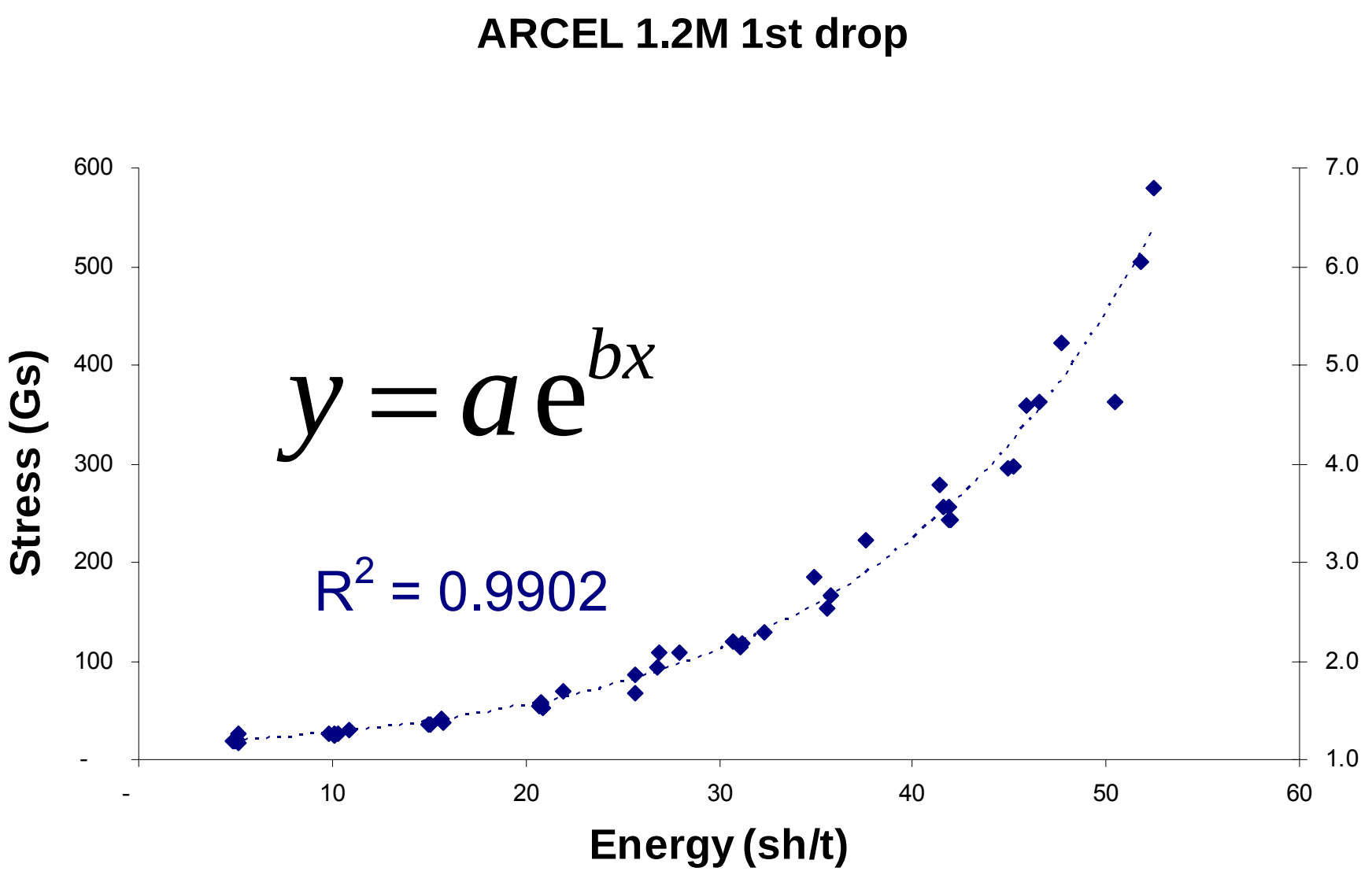
Step 2 Divide the energy range in Step 1 into about 10 approximately evenly spaced points. If the range 1 to 48 is used, then test for energies in steps of about 5 psi. You could for example choose 9 different energies equal to 5, 10, 15 . . . . . and 45 in-lb/in$^3$.

Step 3 For *each* of the energies chosen in Step 2, select five different combinations of s, h and t values that give this energy. These 5 combinations are in effect "replicates" for each of the energies listed in the range in Step 2. For example, five different combinations of s, h and t that give sh/t = 30 are:

# Case Study: Results

| Sample | Drop # | Area sqinches | Weight lbs | h inches | t inches | G |
|---|---|---|---|---|---|---|
| 30C | 136 | 12.8 | **25.6** | **30** | 2 | |
| 35A | 151 | 12.8 | **32** | **14** | 1 | |
| 50C | 236 | 12.8 | **64** | **20** | 2 | |
| 50A | 226 | 12.8 | **32** | **20** | 1 | |
| 5B | 6 | 38.4 | **19.2** | **20** | 2 | |
| 5A | 1 | 38.4 | **12.8** | **15** | 1 | |
| 5C | 11 | 38.4 | **12.8** | **30** | 2 | |
| 5D | 16 | 38.4 | **32** | **18** | 3 | |
| 5E | 21 | 38.4 | **32** | **24** | 4 | |
| 10C | 36 | 19.2 | **12.8** | **30** | 2 | |
| 10E | 46 | 19.2 | **32** | **24** | 4 | |
| 10D | 41 | 19.2 | **12.8** | **45** | 3 | |
| 10B | 31 | 19.2 | **19.2** | **20** | 2 | |
| 10A | 26 | 19.2 | **12.8** | **15** | 1 | |
| 15E | 71 | 19.2 | **32** | **36** | 4 | |
| 15B | 56 | 12.8 | **19.2** | **20** | 2 | |
| 15C | 61 | 12.8 | **25.6** | **15** | 2 | |
| 15A | 51 | 12.8 | **12.8** | **15** | 1 | |
| 15D | 66 | 12.8 | **32** | **18** | 3 | |

# Case Study: Results



# Case Study: Results

- Stress vs. Energy equation for Arcel 730
  - 1.2 pcf
  - 1.7 pcf
  - 2.2 pcf
  - 3.0 pcf

- **Stress/Energy Equation generated**
- **Cushion properties fully characterized**
- **ANY cushion curve can now be drawn**

# Conclusion

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- Recommendation #1
  - Convert existing cushion curves into Stress/Energy equations
  - Generate new data?

# Calculated Values from Existing Cushion Curves

| Name | Material | Density (pcf) | Impact | A | B |
|---|---|---|---|---|---|
| ARCEL 512 | Arcel | 1.2 | 1 | 18.79 | 0.0543 |
| ARCEL 512 | Arcel | 1.2 | 2-5 | 18.643 | 0.0786 |
| DYLITE D195B | EPS | 1.25 | 1 | 20.655 | 0.0474 |
| DYLITE D195B | EPS | 1.25 | 2-5 | 20.486 | 0.0834 |
| Eperan EPP | EPP | 1.3 | 1 | 12.463 | 0.0782 |
| Eperan EPP | EPP | 1.3 | 2-5 | 13.573 | 0.1007 |
| Eperan EPP | EPP | 1.9 | 1 | 21.312 | 0.0448 |
| Eperan EPP | EPP | 1.9 | 2-5 | 25.443 | 0.0478 |
| Arpro EPP 3413 | EPP | 1.3 | 1 | 13.424 | 0.0735 |
| Arpro EPP 3413 | EPP | 1.3 | 2-5 | 14.065 | 0.0864 |
| Arpro EPP 3419 | EPP | 1.9 | 1 | 22.172 | 0.0445 |
| Arpro EPP 3419 | EPP | 1.9 | 2-5 | 20.779 | 0.0595 |
| Ethafoam Nova | EPE | 1.7 | 1 | 10.666 | 0.1039 |
| Ethafoam Nova | EPE | 1.7 | 2-5 | 9.9059 | 0.1386 |
| Ethafoam HS 45 | EPE | 3.9 | 1 | 18.585 | 0.0586 |
| Ethafoam HS 45 | EPE | 3.9 | 2-5 | 17.786 | 0.0790 |
| Ethafoam 220 | EPE | 2.2 | 1 | 14.538 | 0.0658 |
| Ethafoam 220 | EPE | 2.2 | 2-5 | 14.684 | 0.0881 |
| Ethafoam Select | EPE | 1.9 | 1 | 9.5351 | 0.1003 |
| Ethafoam Select | EPE | 1.9 | 2-5 | 9.8891 | 0.1036 |

# Conclusion

- Recommendation #2
  - Re-visit ASTM 1596?

# Thank You

# Questions?