VARIABLES THAT AFFECT THE INTERNAL STRENGTH OF CROSS-LINKED CLOSED-CELL POLYOLEFIN FOAM

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Introduction

Cross-linked closed-cell polyolefin foams have been used as pressure sensitive adhesive substrates for more than 55 years. These foams can range in density, thickness, and formulation, and the performance can be characterized in many different ways, one being internal strength. The internal strength suggests how strong or resilient a foam may be towards deformation. In the tape industry, this is interesting in the sense that it will help determine how tough the tape is and how much force it will take for a cohesive failure to happen. In this paper, the method to measure the internal strength of cross-linked closed-cell polyolefin foam will be discussed, along with variables that affect the values.

Experimental

Cross-linked closed-cell polyolefin foams ranging in densities from 1.5 pcf to 22 pcf, and thicknesses ranging from 0.014" - 0.500" were used. These foams were made using LDPE, LLDPE, EVA, or PP.

Sample Preparation

To begin, raw materials including olefin resin, additives such as process aids, and chemical foaming agents were introduced to an extruder. The extruder was set to a temperature higher than the melting temperature of the resin, but lower than the activation temperature of the foaming agent. The melt was extruded through a sheet die, cooled, and then collected onto a reel (Figure 1).

The reel was then taken to an irradiation machine where the sheet from the reel was unwound and passed through a high-voltage electron beam to crosslink the polymer via radical chemistry. The cross-linked sheet, visually unchanged, was rewound on to another reel (Figure 2.)

The reel with the cross-linked sheet was taken to an oven where the sheet was once again unwound and dropped vertically into an environment above the activation temperature of the chemical foaming agent that was introduced in the extrusion step. This resulted in the decomposition of the foaming agent and the generation of the cell structures within the sheet. Simultaneously, the sheet expanded in all three directions: thickness, width, and length. The foam was cooled back down to room temperature and wound into rolls (Figure 3.)

Figure 1: Extrusion

Figure 2: Irradiation

Figure 3: Foaming

The roll of foam was taken to another extruder to apply a 0.020” coating of solid LDPE. The foam and the LDPE coating entered a nip roller so the two layers bond together with heat and pressure. The nip gap is set so the foam experienced 50% compression (Figure 4). The process was repeated so both sides of the foam were coated with LDPE. When using a PP foam, LDPE does not bond well, so a PP coating should be applied instead of the LDPE.

After the foam was coated on both sides with LDPE or PP, a 1” x 6” test sample strip was cut in both machine direction (MD) and cross-machine direction (CM). One end of the sample strip was skived approximately 1” deep using a razor knife (Figure 5).

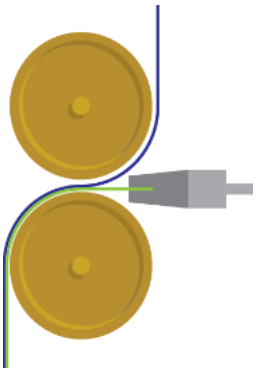


Figure 4: Extrusion Coating

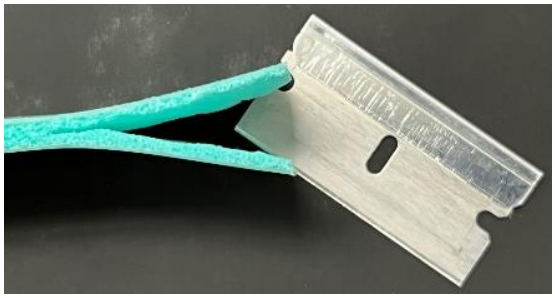


Figure 5: End of sample skived using razor

Test Method

The partially skived test strip was loaded onto a material testing machine. With the testing machine set for extension, the skived ends were pinched by the two grips (Figure 6). The test was run so the grip travels apart to tear the sample at a rate of 10 in/min. The maximum force required to tear the foam was recorded. If no LDPE or PP coating was present, the foam tear would veer to the side. If the bond between the foam and the coating is insufficient, one may observe an adhesion failure where the coating comes off the foam cleanly. Both of these would be an improper test result. Unless otherwise noted, the average of good n=3 data is reported.

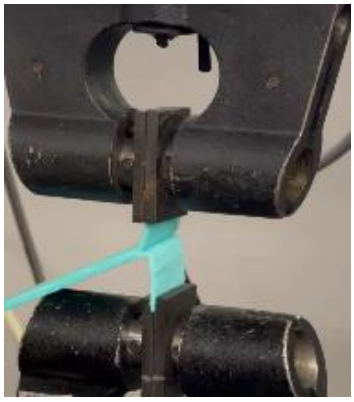
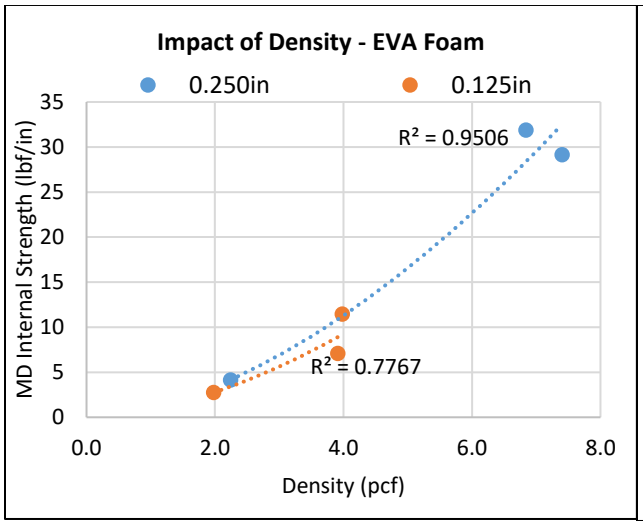


Figure 6: Sample set in the material testing machine.

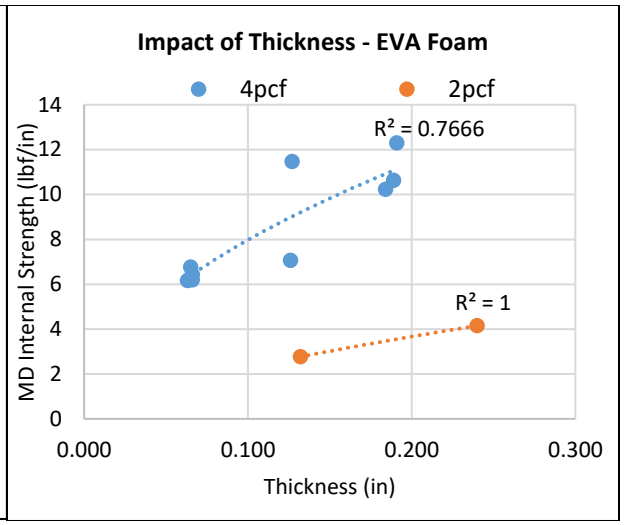
Results

Density, Thickness, Basis Weight

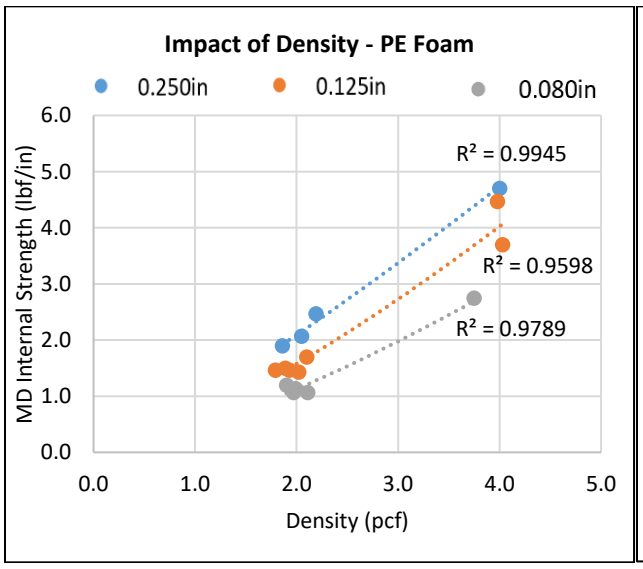
EVA and LDPE foams ranging in densities of 2.0 – 7.0 pcf and thickness of 0.063" – 0.250" were compared. In both cases, the internal strength increased with increasing density and increasing thickness (Graphs 1-4). By multiplying the density and thickness, the basis weight was calculated. Basis weight describes how much mass is present in a given area. Based on this metrics, it is clear the internal strength increased with increased basis weight. It also shows that EVA foam has a higher internal strength than LDPE foam (Graph 5).



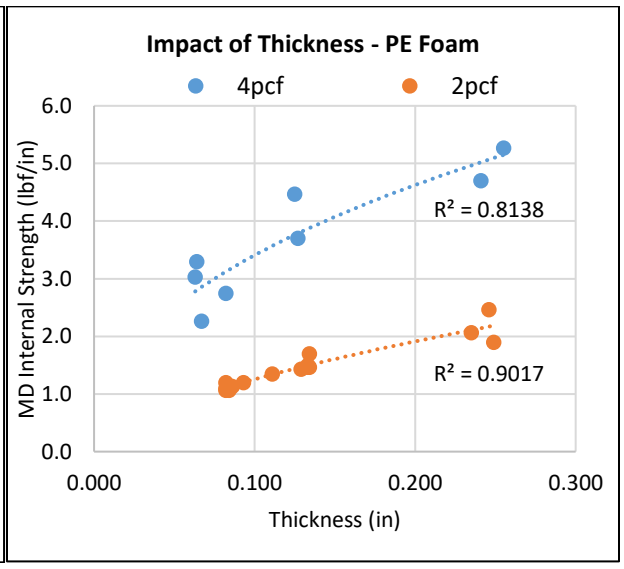
Graph 1



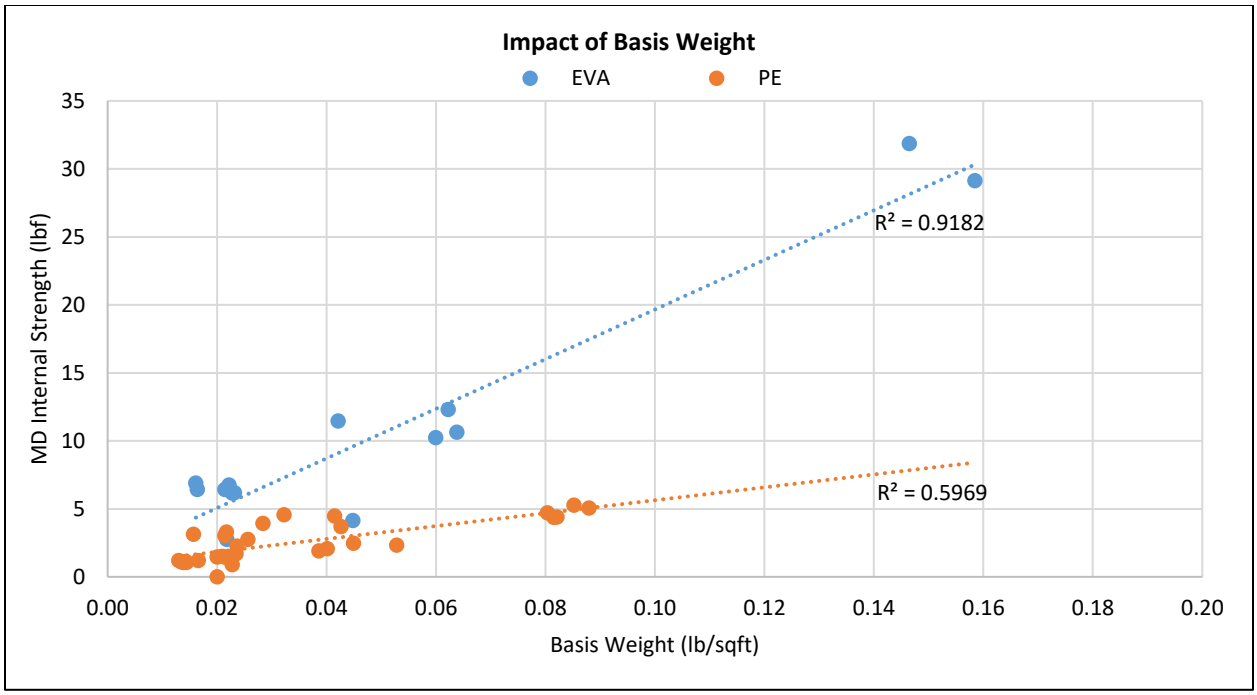
Graph 2



Graph 3



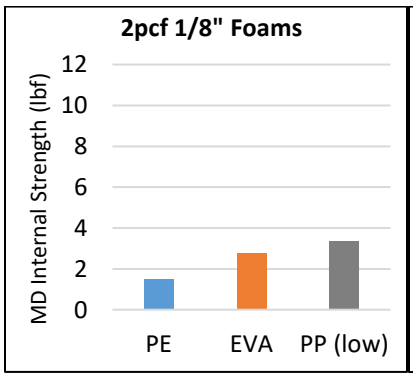
Graph 4



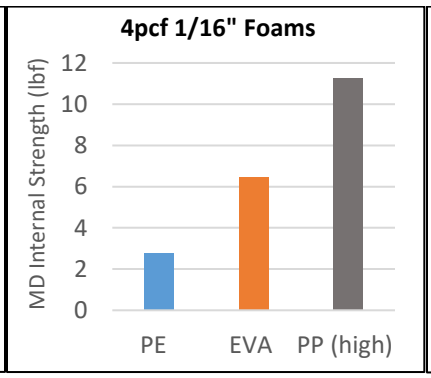
Graph 5

Resin Type

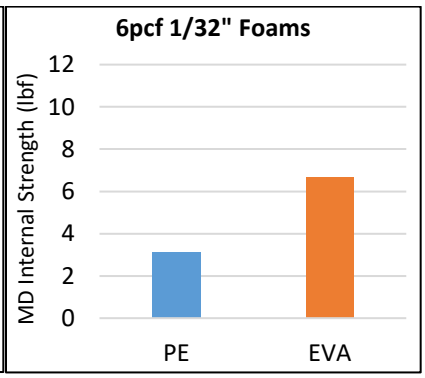
From the EVA, PE, and PP families, foams that were roughly 2 pcf 1/8" thick, 4 pcf 1/16" thick, and 6 pcf 1/32" thick were selected. In all cases, the internal strength ranked in the order of PE, EVA, and PP. The PP specimen from the 4 pcf 1/16" sample pool has more PP% than the PP specimen from the 2 pcf 1/8" sample pool. As a result, the internal strength difference between the PP and EVA specimen was greater for the 4 pcf 1/16" sample pool (Graph 6 & 7). A good 6 pcf 1/32" PP specimen was unavailable, thus this comparison is limited to EVA and PE (Graph 8). Results from this comparison compliments the results shown in Graph 5 well.



Graph 6



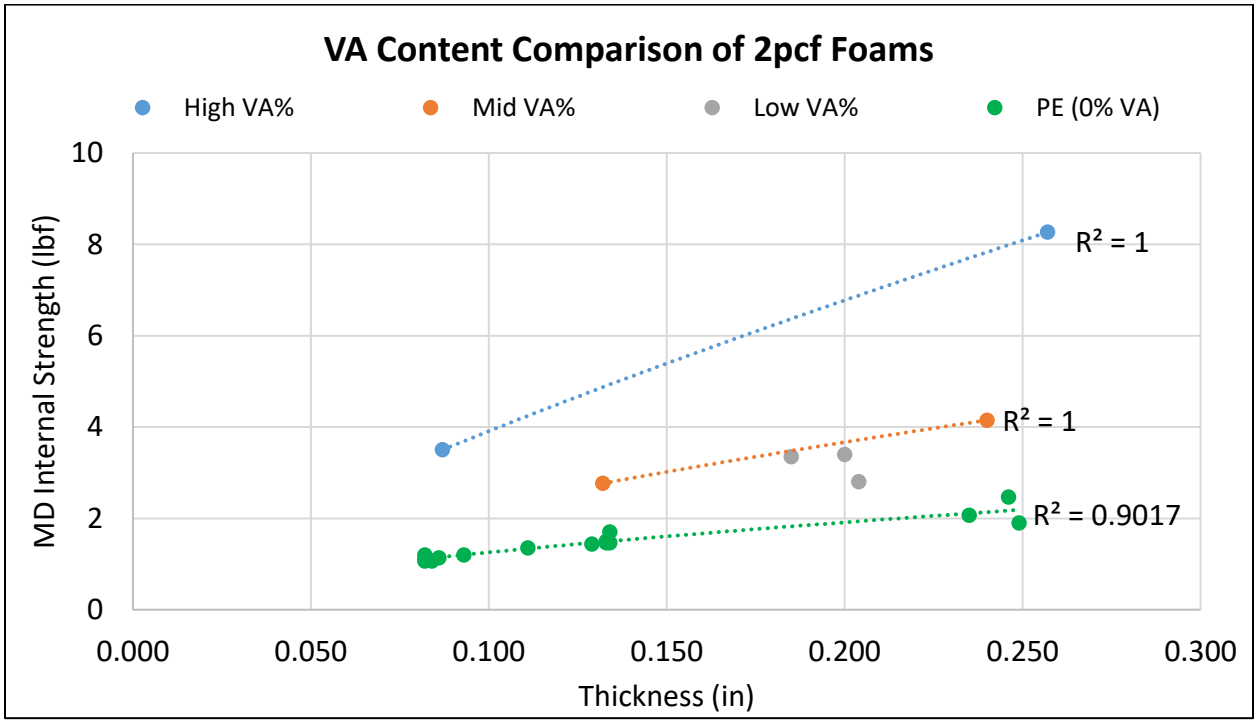
Graph 7



Graph 8

VA Content of EVA

Molecularly, EVA is LDPE with the vinyl acetate (VA) functional group attached to the carbon chain. Depending on the amount of VA content, the properties of the EVA and the foam made from it will change. Here, the internal strength of 2pcf LDPE foam and 2 pcf EVA foams with low, medium, and high VA content are compared (Graph 9). An increase in internal strength can be observed with increasing VA%.



Graph 9

Cell Size

The cell size of the foam is a significant influencer to the foam's performance. Here we have two 2 pcf 1/8" thick LDPE foams, but the cell size of one of them is 0.016" whereas the second sample is 0.035". This roughly double-in-size difference resulted in a 25% reduction in the internal strength of the sample with the larger cells (Figure 7 & Graph 10).

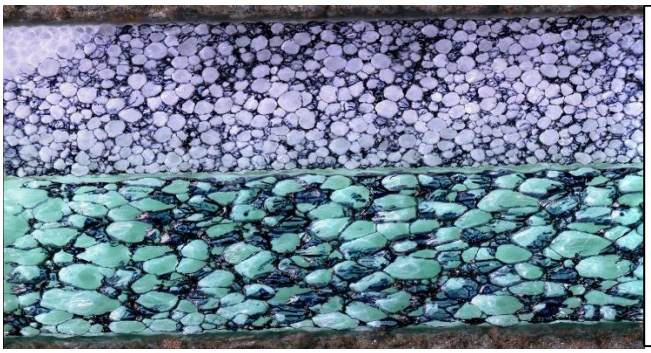
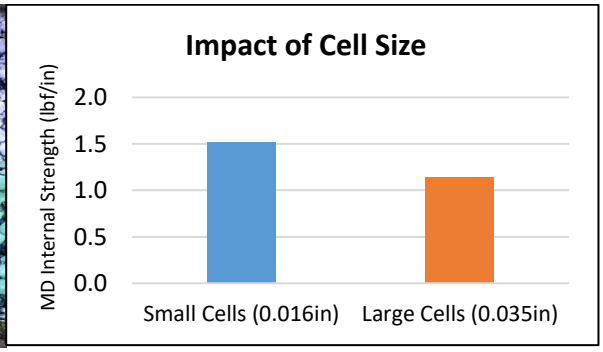


Figure 7: Cell size comparison of 2 pcf 1/8" thick LDPE foam. Top: 0.016" Bottom: 0.035"



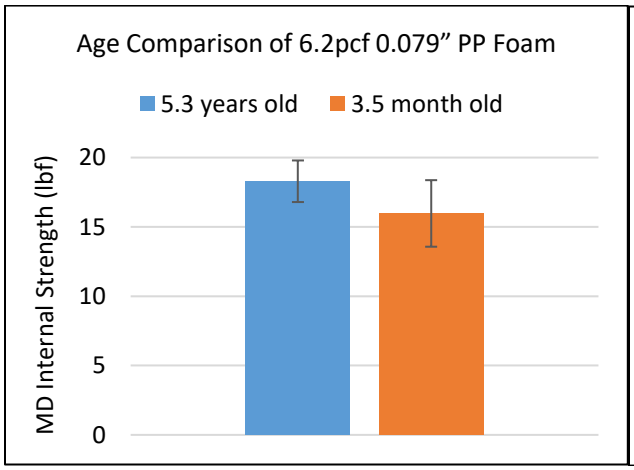
Graph 10

Foam Age

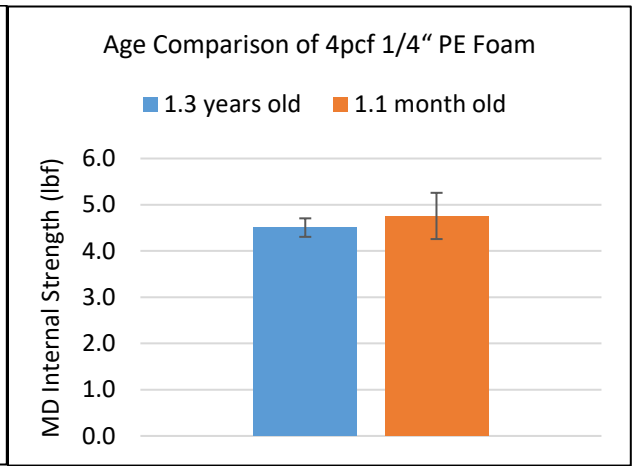
A frequent concern that is brought up is the performance of an aged foam. For this comparison, four samples were identified with foam ages ranging from 1.1 month old to 5.3 years old. The storage conditions of each sample are noted in Table 1. For this test, the average of n=10 was used and 1 sigma is shown on the graphs (Graph 11 & 12). The results show that there was no significant difference between the young and old foam for both the PE and PP samples.

Table 1: Storage conditions of foams used to test the impact of age on the internal strength

	Location	Condition	Climate Control?	Bagged?
Old PP	Indoor	Dark	No	No
New PP	Indoor	Dark/Light	No	Yes
Old PE	Indoor	Dark/Light	No	Yes
New PE	Indoor	Dark/Light	No	Yes



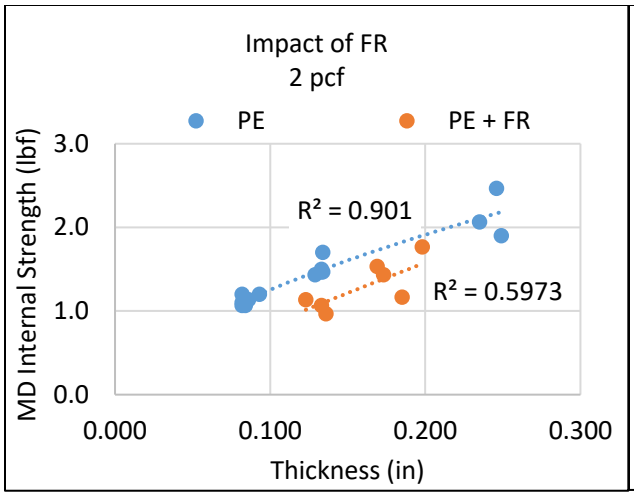
Graph 11

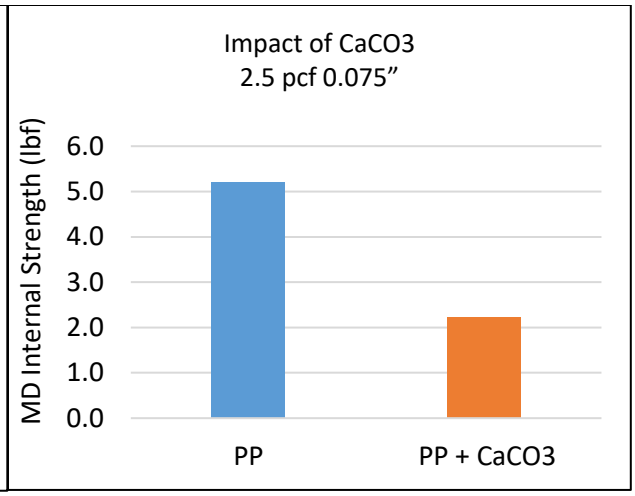


Graph 12

Fillers

A foam's performance can change by introducing additives. However, these additives can also be considered a filler – a chemical that is not plastic and therefore takes up a portion of the total composition. In this analysis, two sets of samples were evaluated, one with flame retardant added and the other with calcium carbonate added as fillers. In both cases, the added filler reduced the percent of plastic composition, and therefore the internal strength of the foam was reduced (Graph 13 & 14).

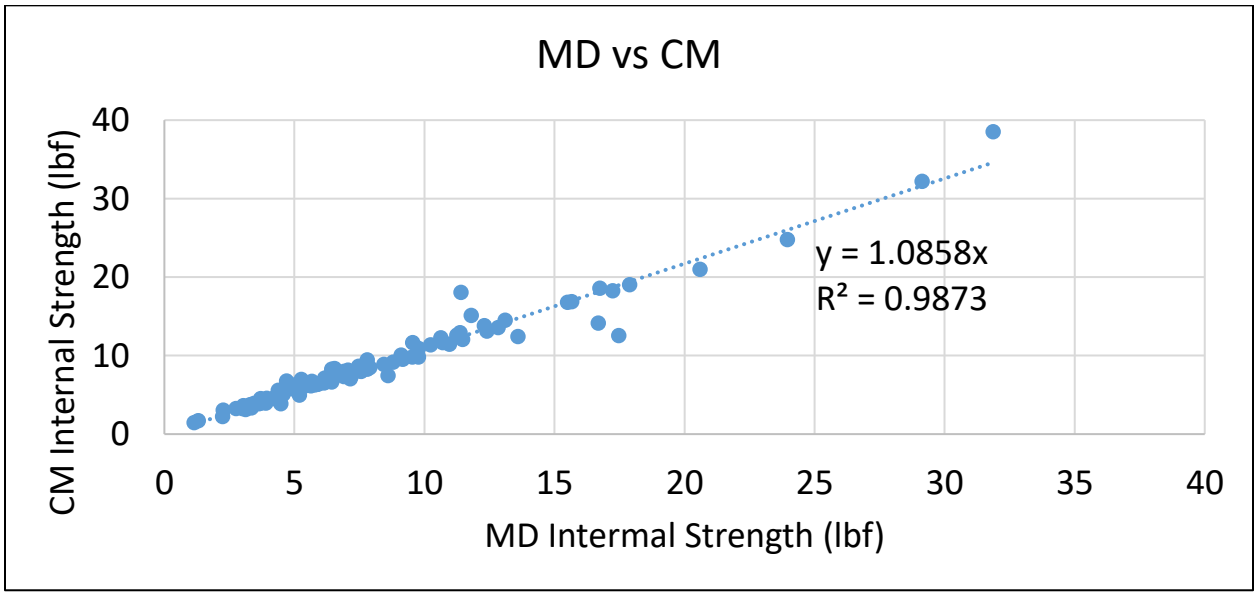




Graph 13 **Graph 14**

MD vs. CM

Thus far, all the data discussed has been for MD. Here, we take a look at relationship of MD and CM. Graph 15 shows the plot of MD internal strength vs. CM internal strength of all the samples that were measured. Most of the time, the CM value is greater than the MD value. The slope of 1.0858 signifies that on average, CM values are 8.6% greater than the MD values. This is likely due to the cell shape. Due to the vertical foaming process, the cells of these foams were slightly elongated in the MD. As a result, when the foam was torn in half, less of the cell wall was encountered per distance when tested in the MD, whereas more cell walls were encountered per distance when tested in the CM.



Graph 15

Conclusions

It has become apparent that internal strength of a foam is impacted by multiple characteristics. Material wise, the internal strength increases in the order of PE, EVA, and PP. Strictly within the EVA family, greater VA content increased the internal strength. From a physical characteristic point of view, as one might have expected, higher density and greater thickness, or the higher basis weight, increased the internal strength. The presence of filler reduced the internal strength, as it interferes with the carrier plastic. The age of the foam surprisingly, but thankfully, did not negatively impact the internal strength. Finally, the cell structure of the foam played an interesting part to the internal strength. Not only did smaller cells prove to have higher internal strength, but the shape of the cells had an influence to the point that CM internal strength was almost always stronger than MD.

Acknowledgements

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