Strong Feelings For Softness: A Comparative Study Of US Towel Production

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ABSTRACT

How are softness and other physical attributes of paper towels related? To evaluate this, a comparative study was conducted on a large variety of paper towels sold in the US, both leading national and regional label brands. The experimental emphasis was on softness and strength properties and other attributes were reviewed. The results revealed two major points: Paper towel brands have a wide range of both strength and softness values and that there is little or no differentiation in these attributes between national and regional brands. One positive correlation identified that products manufactured with structure could be expected to have both increased softness and wet strength.

1. INTRODUCTION

The global market for paper tissue and towel products has been one of the strongest growing segments of the forest products industry in recent years. Including both at-home and away from home sectors, the North American market alone accounts for nearly 10 million metric tons of tissue and towel consumption. Kitchen toweling represents approximately 1/3 of the nearly 6 million metric tons of North American at-home tissue and towel consumption and has experienced the fastest relative growth of all tissue and towel products.[1] This success is partially explained by a variety of new developments in manufacturing technology which allow for production of softer, stronger sheets. In fact, while strength and absorbency remain key selling points for at-home paper towels, sheet softness has also emerged as a primary focal point for many towel producers. This is evidenced by the considerable amounts of capital invested in new machines capable of producing textured sheets with excellent softness properties as well as new chemicals developed to help facilitate both strength and softness.

Unfortunately, sheet softness is a rather ill-defined property with no all-encompassing testing method available to describe it. Typically, large companies and consumer groups rely on subjective hand panel testing for softness measurements. While useful, hand panel testing has many drawbacks, with a major one being the lack of resources across all manufacturers which results in infrequent hand panel meetings and limited sample testing capacity. As an unintended consequence of this, machine operators have limited opportunities to receive timely feedback on how various process controls affect final sheet softness. Additionally, as all manufacturers use different methodology in hand panel testing, there is currently no unified scale across the industry, causing a "shroud of mystery" surrounding how the industry stands as a whole in regards to towel softness. The primary goal of this article is to help fill this knowledge gap by testing a wide range of at-home consumer paper towels, with particular attention paid to softness and strength. It should be noted here that water absorbency was also measured, but no significant differences were observed between the towels tested, therefore the data will not be reported in this article.

To measure sheet softness, we chose to utilize the Emtec® Tissue Softness Analyzer (TSA). The Emtec TSA is a relatively new technology which is commercially available, portable, and represents an objective analytical tool for determining sheet softness. Briefly, it operates by detecting the sound produced by running a set of blades over a fixed paper towel sample and subsequently determining the sheet response to an applied force. It combines a set of data determined from these measurements into a proprietary algorithm which gives a single hand feel (HF) number characterizing the softness of the sheet. Towel mechanical properties (wet and dry tensile) and water absorbency were determined using standard TAPPI testing methodologies.

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[1] Kalil, B. (2008). Tissue market continues to grow. *Pulp & Paper Int'l Digital Edition*. [Online]. Available: http://legacy.risiinfo.com/magazines/pulp-paper/magazine/october/2008/PPMagOctober-Tissue-market-continues-to-grow.html. [Accessed: 2016-1-12].

This study categorized each brand of paper towel into two broad groupings: national brands and regional brands. National brands were selected as those that have the widest geographic availability and are found in most big box chains, major and minor retail grocery stores and are prominently advertised in newspapers, magazines, television and the internet. Regional brands include store and private label brands and are generally only found in retail chains with limited geographic areas. As a point of interest, we further segregated the towels based on claims or advertisements appealing to the consumer's interest in recycling content (i.e. any recycled content versus virgin pulp) and general production type (i.e. structured sheets versus conventional wet press sheets), to see how each correlates to towel softness. It should be noted here that if there were no claims of recycled content on the paper towel packaging, then that brand was included in the virgin pulp category. However, we do recognize that some towel producers use secondary fiber when economical to do so, but do not necessarily make claims to that effect on their packaging. Nonetheless these products were categorized as "virgin".

Contrary to conventional wisdom, data collected here did not show any distinctive correlation between softness and strength. Therefore, this study should not only serve as a survey of current softness of at-home towels across the industry, but it should also be a foundational starting point to better understand the complex duality of softness and strength.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

In total, 82 commercially available at-home paper towel brands were collected from stores in three regions: the south/southeast (Atlanta, Baton Rouge, Houston), northeast (upstate New York), and north/Midwest (Wisconsin). Prior to any measurement, the sheets were stored in a controlled environment room conforming to TAPPI standards (22 °C, 50% RH) overnight.

Emtec TSA testing requires knowledge of both the basis weight and caliper of the sheet prior to it being measured. These were determined using standard testing methods TAPPI T 410 om-08 (basis weight) and TAPPI T 411 om-97 (caliper).

The mean basis weight and caliper for each specific towel brand was obtained using 16 individual sheets from a roll of towels.

2.2 Mechanical Properties

Both the wet and dry tensile strength of each conditioned sample were measured per the following TAPPI standards: TAPPI T 456 om-10 (wet tensile strength) and TAPPI T 494 om-01 (dry tensile strength). The wet and dry tensile strengths presented herein are averaged from a total of 16 measurements (i.e. sixteen individual sheets were measured from a towel roll from each brand).

2.3 Water Absorbency

Water absorbency of the towels was determined using TAPPI T 831 om-09. As mentioned, however, we did not observe any significant differences in any towel, therefore those data have been omitted from this report.

2.4 Softness Analysis

The Emtec TSA being a relatively new technology it might be useful to briefly describe its operation. First, a sample sheet is placed into the TSA and clamped into place (see Fig. 1). The entire structure where the sheet is held sits on a balance which is used to measure applied forces. Directly under the sheet is a microphone embedded into the balance

apparatus. A set of blades approaches the sheet and applies a constant 100 mN force to the surface. The blade then turns on the sheet for 1.5 seconds while the microphone records the vibrational sound. After this sound is recorded, the blade applies a 600 mN force, removes it, and reapplies a 600 mN force using a constant loading rate.

From this process the following variables are obtained: $TS750$, $TS7$, f_{TS750}, E, D, H, and P. Broadly speaking, $TS750$, $TS7$, and f_{TS750} all correspond to the macro-structure of the finished sheet and the intrinsic "softness" of the fibers comprising the sheet. E, D, H, and P are related to the mechanical compliance of the sheet as a whole under loading. A combination of any of these variables with sample basis weight, caliper, and number of plies is then used to calculate the overall softness of the sheet, referred to as hand feel (HF).

Due to the nature of the measurement, there is a strong possibility for a difference in HF measured on the top (side of sheet facing outwards on the roll) and bottom (side of the sheet facing inwards on the roll) of the finished sheet. Therefore, the HF values reported here are the arithmetic means taken from measurements on the top of 8 sheets and the bottom of 8 sheets.

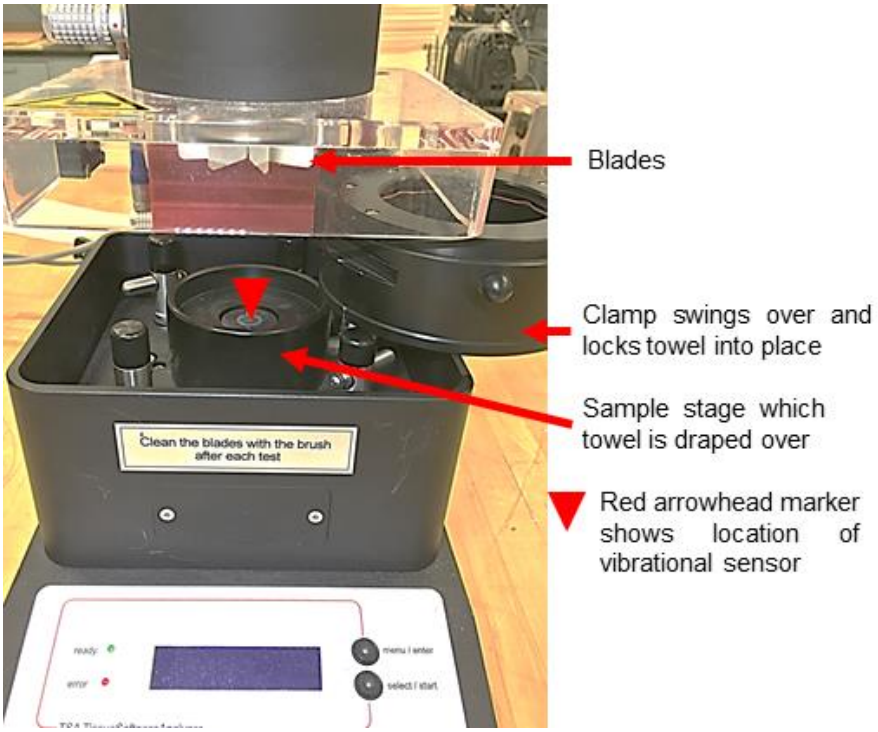

Figure 1: Emtec TSA machine used for determining sheet softness in this study.

3. DISCUSSION AND RESULTS

Of the 82 samples of commercial paper towels obtained, 12 were designated as national and 70 as regional. The packaging of 11 brands collected displayed claims of some amount of recycled content in the paper towel. Twenty-five towel brands were some type of structured sheet. We defined structured sheet to mean any sheet not made on a conventional wet press paper machine. Determination of structured sheet versus conventional sheet was undertaken using visual inspection. Appendix Table 1 contains a list (brand names omitted) of each brand indicating national/regional, recycled claim/no recycle claim, structured/non-structured classifications. Appendix Table 2 contains the tensile properties of each sample and softness calculated from the Emtec TSA (HF).

Because the Emtec TSA is a relatively new technology that is not associated with any TAPPI standard testing methodology, we found it prudent to perform a repeatability and reproducibility study to confirm its usefulness in measuring the softness of the paper towel samples. Briefly this type of study estimates the experimental variation caused by the measurement equipment itself (repeatability) and that caused by how different operators perform the test (reproducibility). In our study 3 operators measured the softness (HF) of the top side of 8 sheets from each of 3 paper towel brands, and repeated this testing twice (i.e., the top side of 24 sheets from each of the 3 brands were measured by one operator). Figure 2 shows a summary of the repeatability and reproducibility testing, with green dots representing each individual sample set's deviation from the overall sample mean. The solid blue lines represent the operator's mean deviation from the combined global mean of all samples. From this plot, it is seen that the operator-to-operator variation is very low, signifying a reproducible testing method. The estimated variations from the Emtec TSA, the operators, and the samples themselves are collected in Table 1. In our study sample-to-sample variation represents the largest component of experimental noise, with a combined %R&R exhibiting only 4.6% variation to the total. According to Automotive Industry Action Group (AIAG) gage repeatability and reproducibility acceptance criteria,[2] measurement systems containing %R&R contributions less than 10% are generally considered to be acceptable. Therefore, we believe that the Emtec TSA is suitable for comparing HF values for the 82 paper towel brands we have collected here. We also found from this testing that the mean standard deviation for HF from the three operators was ~3.36, which indicates that. HF differences are only expected to be statistically significant once they begin exceeding ~3.

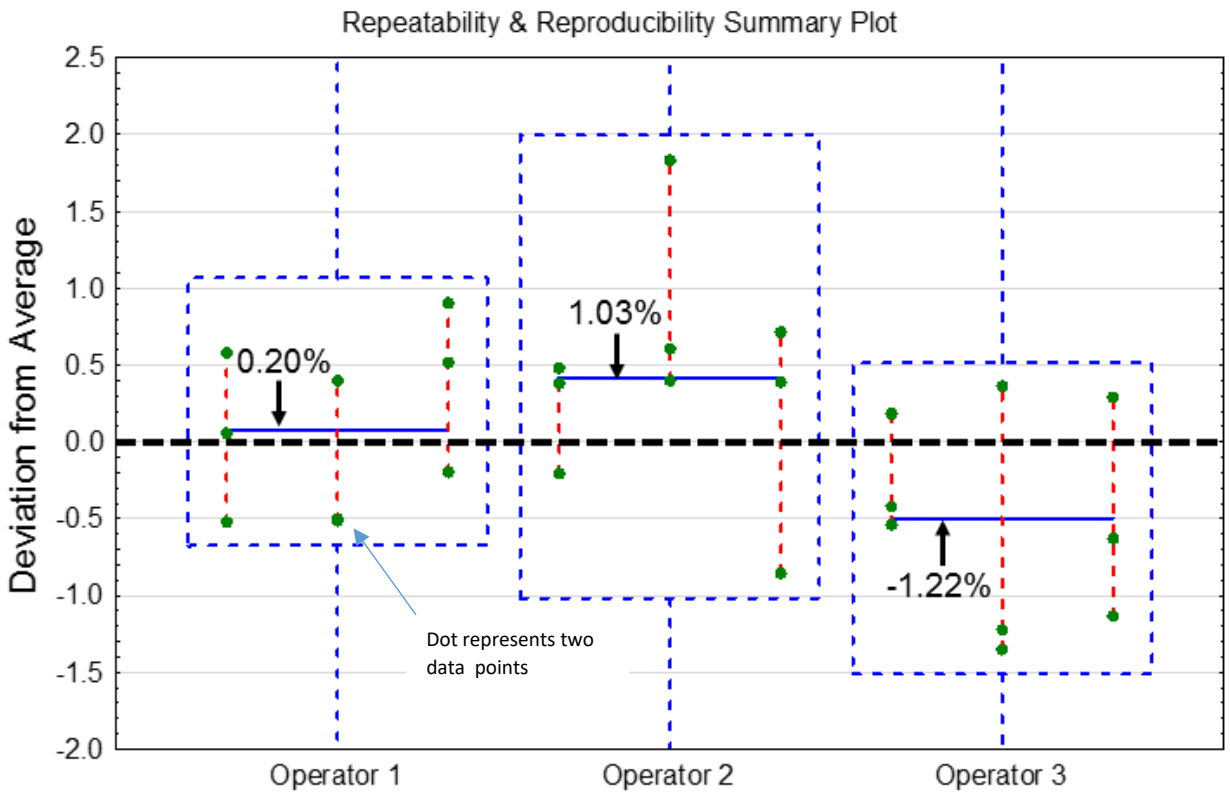

Figure 2: Repeatability and reproducibility summary plot showing the mean deviation obtained by three operators measuring three samples with three times. Each datapoint equals the mean of 8 sheets of one brand.

[2]from *Measurement Systems Analysis*, 4th Edition, 2010, AIAG.

Table 1: Estimated experimental variance by source.

Source	Estimated Variance	% of Total Estimated Variance
Repeatability	0.47650	3.3253
Reproducibility	0.17562	1.2256
Part-to-Part	13.67726	95.4490
Combined R & R	0.65212	4.5510
Total	14.32939	100.0000

Scatter plots of the raw softness values as well as the MD wet and MD dry tensile strengths for each sample are collected in the appendix of the article (Fig. A1, Fig. A2, and Fig. A3). mean *HF* values ranged from 13.7 to 58.0, with a mean of 38.5 ± 7.6 (Mean ± Std. Dev). We further compared each of our classifications (e.g. regional brands versus national brands, etc.) by constructing a regression tree graph (Fig. 3, for additional information see Fig. A4 in the appendix). The top node represents the mean *HF* for the entire sample population. This node is split based on which categorization gives the most significant difference in mean, and further node splitting occurs until the difference in mean is below a 0.95 confidence interval. In Fig. 3 it is seen that structured sheets had *HF* values nearly 30% higher than non-structured sheets (45.4 structured versus 35.5 non-structured), with a p-value ≈ 0, indicating high statistical significance.

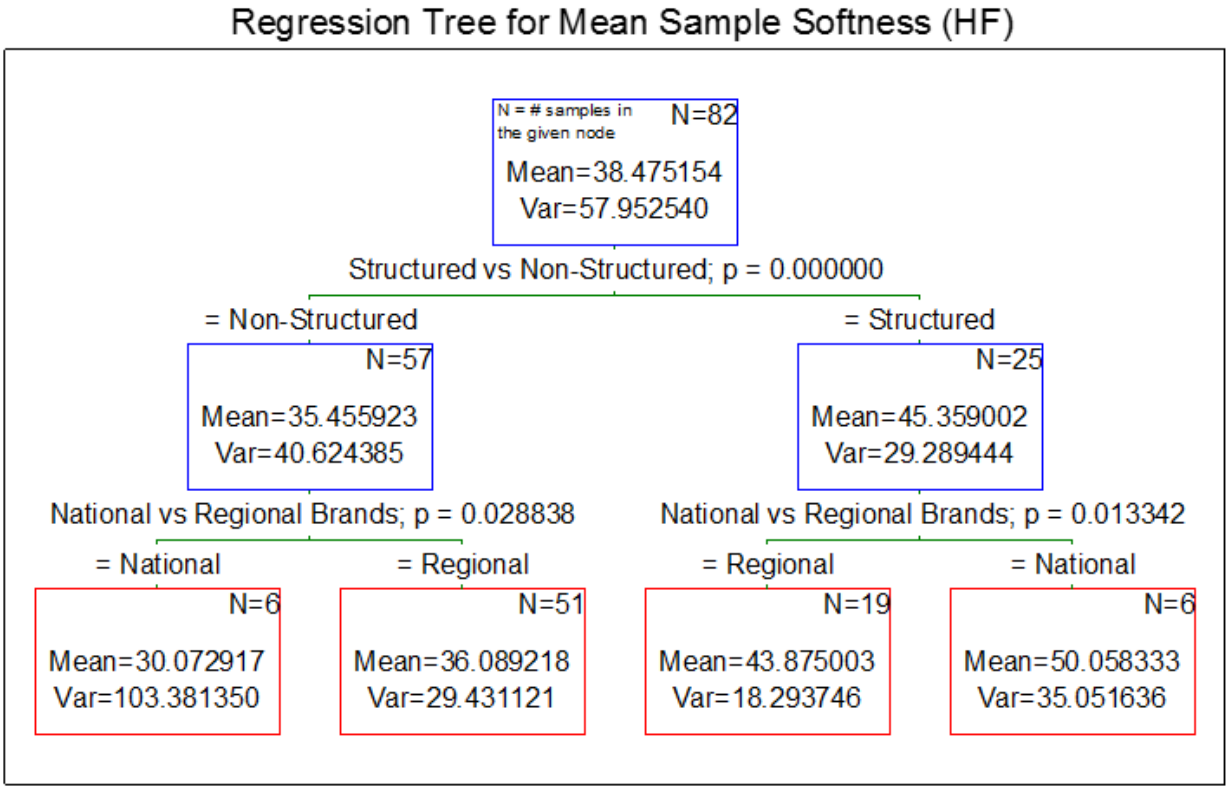

Figure 3: Regression tree graph showing classifications which give statistically significant differences (0.95 confidence interval) in softness. N = number of samples in the given node, Mean = arithmetic mean of N samples in the given node, and Var = variance of N samples in the given node. Explanation of Regression Trees available in Figure A4.

The next significant branch occurs with national versus regional brands. In the case of structured sheets, national brands had higher softness values than those of regional brands. Contrarily, for non-structured sheets, regional brands tended to have higher mean softness values than those of national brands. However, there were two anomalies present in the mean softness values (shown in Fig. A1). The lowest two HF values within the national brand group are most likely skewed lower due to high sheet texture (e.g. to enhance scrubbing power of the sheet). The large-scale texturing in our opinion did not make these sheets feel significantly less soft than the mean HF, however, it is possible that this texture causes abnormally high values of $TS7$ and $TS750$ $variables$, resulting in a low calculated HF. Notably, there were no significant effects on sheet softness in those brands claiming the inclusion of post-consumer recycled materials.

A good graphical visualization of each node split is found in box-whisker plots presented in Fig. 4.

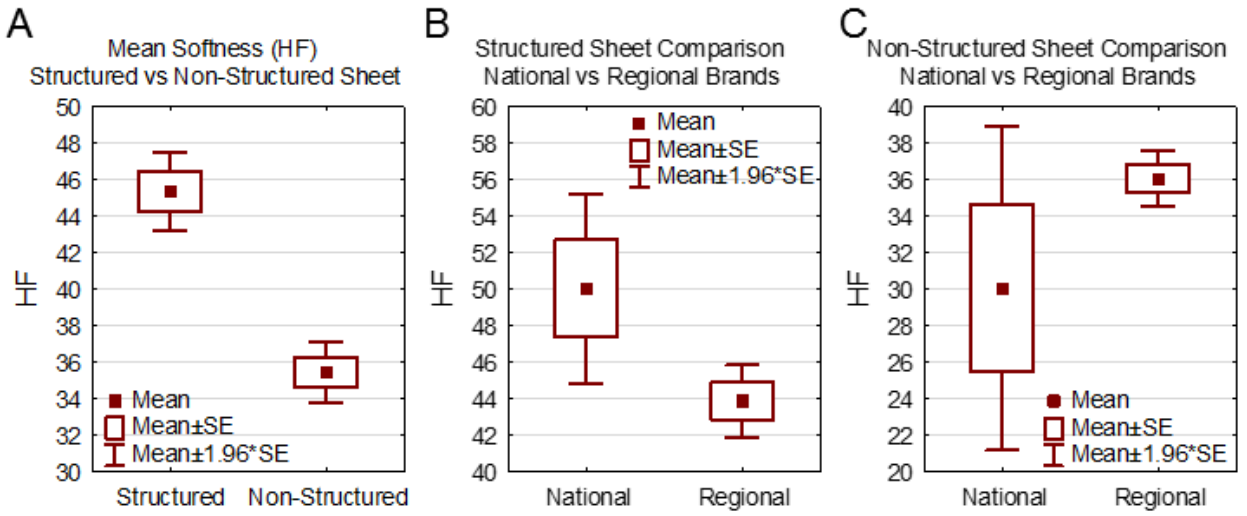

Figure 4: Box and whisker plots showing the mean and standard errors (SE) softness values at the three regression tree node splits: (A) structured sheet vs non-structured sheet, (B) national vs regional brands for structured sheets, and (C) national vs regional brands for non-structured sheets.

In Fig. 4C the spread of the data for the non-structured national brands is higher due to the two anomalies. Excluding these two values from consideration renders the difference between national and regional brand non-structured sheet statistically insignificant (Fig. 5).

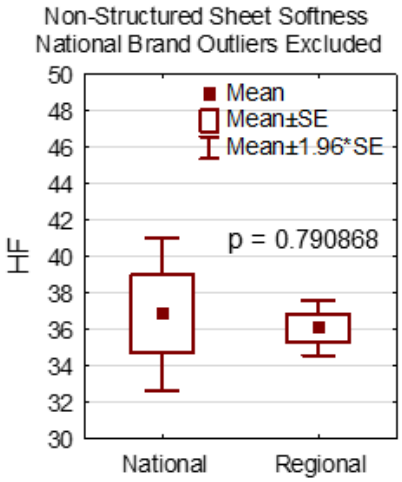

Figure 5: Box and whisker plot showing the mean and standard errors (SE) for national vs regional brand softness for non-structured sheet, excluding the two outliers described in the text.

A similar analysis was performed on MD wet tensile strengths obtained in this study (Fig. 6). The mean MD wet tensile strength across all paper towels was found to be 0.53 ± 0.22 lbf·in^{-1}. We found that again the classification with the most statistical significance was between structured and non-structured sheets, with structured sheets having approximately 30% higher MD wet tensile strengths ($p = 0.002448$). Within the structured sheets there was no significant difference between national and regional brand wet tensile strengths. However, national brands did outperform regional brands in wet tensile strength for non-structured sheets.

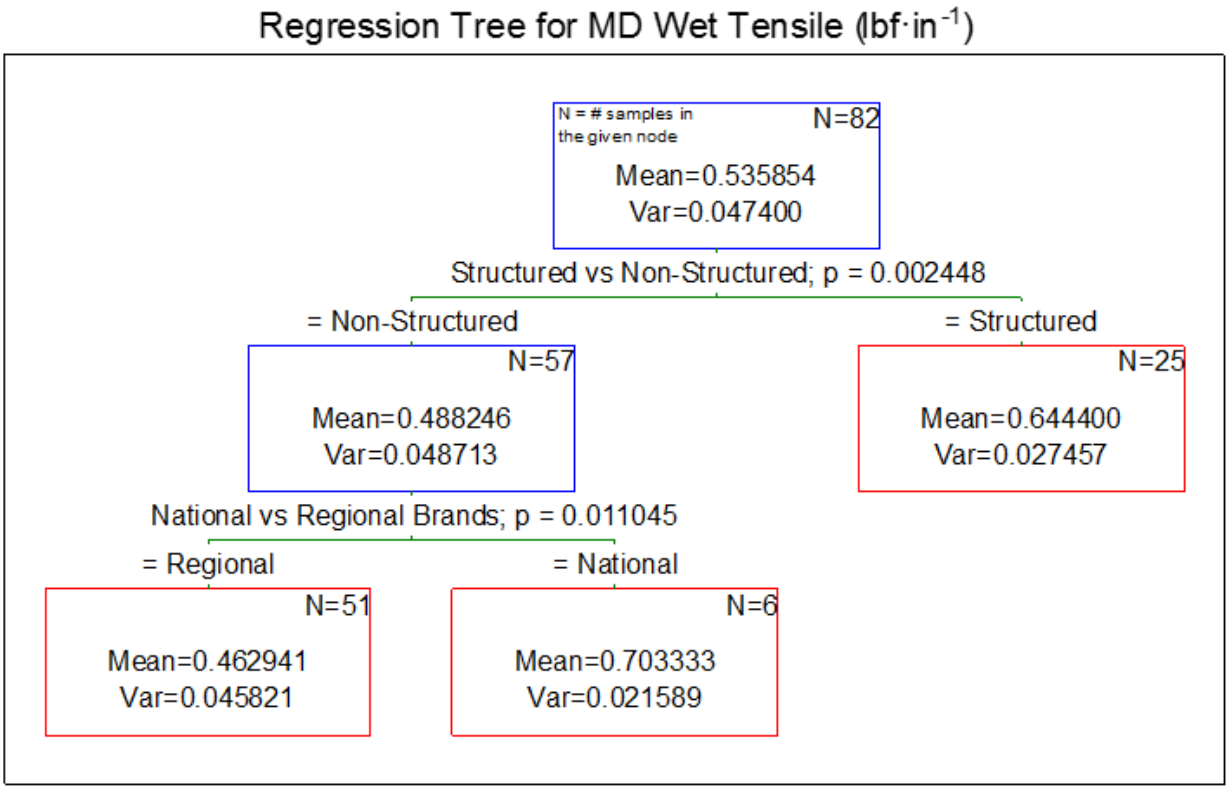

Figure 6: Regression tree graph showing classifications which give statistically significant differences (0.95 confidence interval) in softness. N = number of samples in the given node, Mean = arithmetic mean of N samples in the given node, and Var = variance of N samples in the given node. Explanation of Regression Trees available in Figure A4.

Box-whisker plots in Fig. 7 illustrate the node splits for the MD wet tensile strength values. While it is not within the scope of this study, it is interesting that when it comes to wet strength and softness, structured sheets and national brands tended to outperform non-structured sheets and regional brands. The more energy intensive manufacturing process tends to drive the prices of structured sheet products upwards. Additionally, leading national brands tend to be higher in price than their regional competitors. However, what we see in this study is that the products typically associated with higher prices here do tend to have higher softness and higher wet tensile strength.

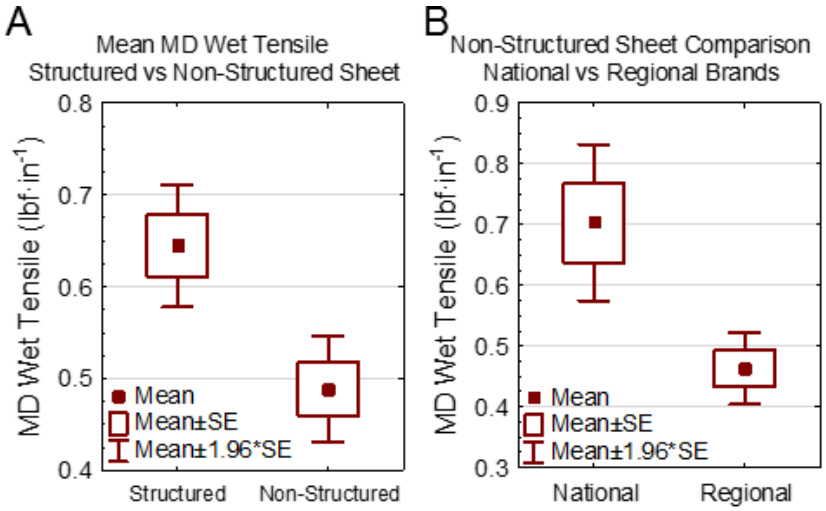

Figure 7: Box and whisker plots showing the mean and standard errors for MD wet tensile strengths at the two regression tree node splits: (A) structured sheet vs non-structured sheet, (B) national vs regional brands for non-structured sheets.

The mean MD dry tensile strength for all brands tested was found to be 2.27 ± 0.71 lbf·in^{-1}. Contrary to both softness and MD wet tensile strength, none of the three classifications used here showed any statistically significant differences in dry tensile strength. This observation is presented in Fig. 8.

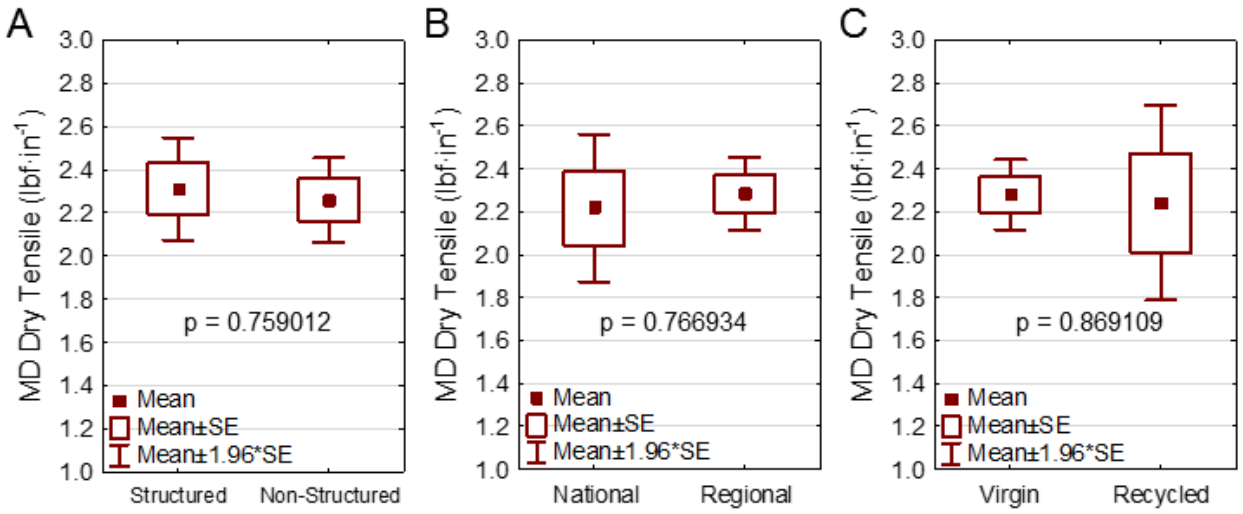

Figure 8: Box and whisker plots showing the mean and standard errors for MD dry tensile strengths for the three sample classifications: (A) structured sheet vs non-structured sheet, (B) national vs regional brands, and (C) virgin pulp vs inclusion of recycled pulp claims.

Another peculiar result of this study is that in no case did the known inclusion of recycled materials into the manufacturing process significantly affect the final end-product results. This may point to our assumption of no claims of recycled content on the packaging meaning that only virgin fiber was used (when in fact that may not have been the case) being an oversimplification. Or perhaps the creping process destroys the tensile properties of virgin fibers enough that the impact of the addition of secondary fibers on the tensile properties of the sheet is negligible. This could be an interesting focal point for future studies.

A scatter plot of mean softness versus mean dry tensile strength is presented in Fig. 9A. Conventional knowledge is that sheet softness should be inversely proportional to dry tensile strength. For example, many of the chemical agents added into the wet end of the paper machine to increase apparent softness and sheet lubricity are designed to break up the strong inter-fiber bonding of the final sheet, resulting in a lower overall dry tensile strength. Here we see much more scatter than expected, however, with a low correlation between softness and strength ($r^2 = 0.05$). We also found that no single brand tested provides simultaneously the highest softness and the highest dry tensile strength values.

The wet tensile strength (Fig. 9B) of the samples showed even lower correlation to sheet softness in comparison to dry tensile strength ($r^2 = 0.003$). In general the wet tensile strength of the paper towel is a more important performance indicator than the dry tensile strength due to the product's intended use. Within our sample set, however, we again did not observe any brand with a combination of the highest softness and highest wet tensile strength values.

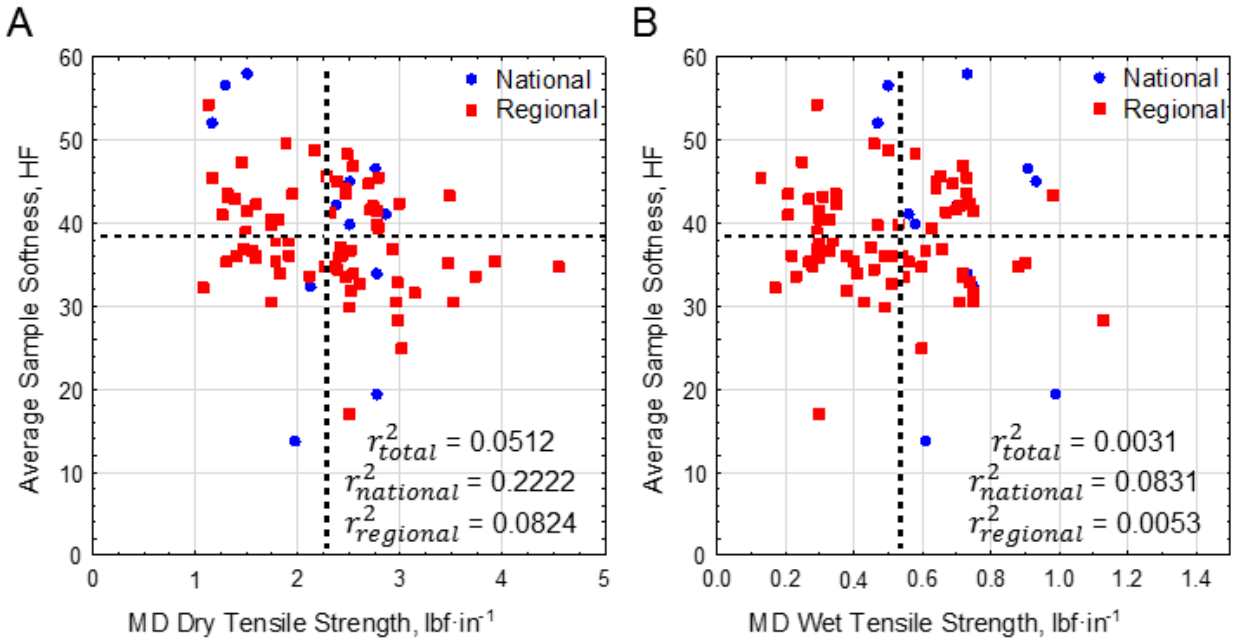

Figure 9: Softness versus MD dry tensile strength (A) and MD wet tensile strength (B). Dashed black lines represent the mean of value of each corresponding axis.

5. CONCLUSIONS

One unexpected discovery in these experiments using the Emtec TSA was that heavily embossed and textured sheets can give skewed results (low numbers). For this reason hand panel testing will still be important for final product quality assurance. Nevertheless, this machine does seem optimally suited for comparative studies and, perhaps more importantly, has the potential to provide timely base sheet softness feedback to machine operators. Additional studies will be conducted to compare hand panel testing to the results we have presented here.

We did not observe any noteworthy correlation between dry tensile properties and softness as previously believed, suggesting a more complicated interplay between these two parameters. Overall comparison of the properties measured show that both national and regional brands tend to a mean value. We did, however, see that structured sheet products in general have both higher softness and wet strength values. Ultimately we found no one brand that simultaneously exhibited both the highest strength and the highest softness values. This then raises the question – is having both highest softness and highest strength an unobtainable goal for any particular towel product, or is it to be seen as a gold standard towards which towel manufacturers will strive?

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Table A1: Sample numbers and corresponding categorical descriptors used in this study.

Sample No.	National/ Regional	Virgin/ Recycled Content	Structured/ Non-Structured	Sample No.	National/ Regional	Virgin/ Recycled Content	Structured/ Non-Structured	Sample No.	National/ Regional	Virgin/ Recycled Content	Structured/ Non-Structured
1	National	Virgin	Structured	29	Regional	Virgin	Non	57	Regional	Virgin	Non
2	National	Virgin	Non	30	Regional	Virgin	Structured	58	Regional	Recycled	Structured
3	National	Virgin	Non	31	Regional	Virgin	Non	59	Regional	Virgin	Non
4	National	Virgin	Non	32	Regional	Virgin	Structured	60	Regional	Virgin	Structured
5	National	Virgin	Structured	33	Regional	Virgin	Structured	61	Regional	Virgin	Non
6	National	Virgin	Structured	34	Regional	Virgin	Structured	62	Regional	Virgin	Structured
7	National	Virgin	Non	35	Regional	Recycled	Non	63	Regional	Virgin	Non
8	National	Virgin	Structured	36	Regional	Virgin	Non	64	Regional	Virgin	Structured
9	National	Virgin	Structured	37	Regional	Virgin	Non	65	Regional	Virgin	Non
10	National	Virgin	Structured	38	Regional	Virgin	Non	66	Regional	Virgin	Structured
11	National	Virgin	Non	39	Regional	Virgin	Non	67	Regional	Virgin	Non
12	National	Virgin	Non	40	Regional	Virgin	Non	68	Regional	Virgin	Non
13	Regional	Virgin	Structured	41	Regional	Virgin	Non	69	Regional	Virgin	Non
14	Regional	Virgin	Non	42	Regional	Virgin	Structured	70	Regional	Virgin	Non
15	Regional	Recycled	Structured	43	Regional	Virgin	Non	71	Regional	Virgin	Non
16	Regional	Recycled	Non	44	Regional	Virgin	Structured	72	Regional	Virgin	Non
17	Regional	Recycled	Non	45	Regional	Virgin	Non	73	Regional	Virgin	Non
18	Regional	Recycled	Non	46	Regional	Virgin	Non	74	Regional	Virgin	Non
19	Regional	Virgin	Non	47	Regional	Virgin	Non	75	Regional	Virgin	Non
20	Regional	Virgin	Structured	48	Regional	Virgin	Structured	76	Regional	Virgin	Non
21	Regional	Virgin	Non	49	Regional	Virgin	Non	77	Regional	Virgin	Non
22	Regional	Virgin	Non	50	Regional	Virgin	Non	78	Regional	Virgin	Non
23	Regional	Recycled	Non	51	Regional	Virgin	Non	79	Regional	Virgin	Structured
24	Regional	Recycled	Non	52	Regional	Virgin	Structured	80	Regional	Virgin	Non
25	Regional	Recycled	Non	53	Regional	Virgin	Non	81	Regional	Virgin	Structured
26	Regional	Recycled	Non	54	Regional	Virgin	Structured	82	Regional	Recycled	Non
27	Regional	Virgin	Non	55	Regional	Virgin	Non				
28	Regional	Virgin	Non	56	Regional	Virgin	Non				

Table A2: Average softness, MD wet tensile strength, and MD dry tensile values recorded in this study.

Sample No.	Softness (HF)	MD Wet Tensile Strength ($lbf \cdot in^{-1}$)	MD Dry Tensile Strength ($lbf \cdot in^{-1}$)	Sample No.	Softness (HF)	MD Wet Tensile Strength ($lbf \cdot in^{-1}$)	MD Dry Tensile Strength ($lbf \cdot in^{-1}$)	Sample No.	Softness (HF)	MD Wet Tensile Strength ($lbf \cdot in^{-1}$)	MD Dry Tensile Strength ($lbf \cdot in^{-1}$)
1	45.0	0.93	2.50	29	39.9	0.53	2.77	57	37.0	0.29	1.47
2	13.7	0.61	1.98	30	43.3	0.98	3.48	58	45.6	0.65	2.28
3	19.4	0.99	2.77	31	41.3	0.67	2.32	59	35.3	0.40	1.78
4	39.9	0.58	2.50	32	43.7	0.73	2.47	60	41.5	0.75	2.77
5	56.6	0.50	1.29	33	48.8	0.50	2.17	61	30.5	0.75	3.52
6	58.0	0.73	1.51	34	45.1	0.64	2.38	62	36.7	0.61	2.52
7	32.4	0.75	2.13	35	35.3	0.27	1.31	63	38.1	0.34	1.91
8	46.6	0.91	2.76	36	34.0	0.72	2.54	64	44.0	0.64	2.47
9	42.1	0.70	2.38	37	35.3	0.56	3.93	65	30.5	0.43	1.75
10	52.1	0.47	1.16	38	40.5	0.30	1.81	66	41.4	0.30	1.51
11	34.0	0.73	2.77	39	47.3	0.25	1.46	67	34.0	0.41	1.82
12	41.1	0.56	2.86	40	17.1	0.30	2.51	68	43.5	0.21	1.32
13	49.6	0.46	1.89	41	37.0	0.45	2.42	69	34.8	0.28	2.27
14	42.8	0.27	1.39	42	44.8	0.69	2.70	70	43.5	0.35	1.95
15	36.0	0.54	1.91	43	36.0	0.52	2.40	71	38.9	0.29	1.49
16	36.9	0.66	2.93	44	54.2	0.29	1.13	72	39.8	0.47	1.75
17	33.6	0.55	3.73	45	29.9	0.49	2.51	73	40.6	0.33	1.75
18	34.6	0.60	2.37	46	24.8	0.60	3.01	74	31.6	0.75	3.14
19	34.7	0.88	4.54	47	40.9	0.21	1.27	75	46.9	0.72	2.55
20	42.4	0.74	2.99	48	45.4	0.73	2.78	76	32.2	0.17	1.07
21	33.7	0.23	2.12	49	31.9	0.38	2.52	77	35.8	0.30	1.58
22	36.6	0.33	1.56	50	32.8	0.74	2.97	78	36.1	0.49	2.43
23	34.4	0.46	2.39	51	28.2	1.13	2.97	79	42.0	0.71	2.73
24	30.6	0.71	2.96	52	41.6	0.70	2.71	80	32.6	0.51	2.61
25	43.1	0.31	1.32	53	42.1	0.35	1.59	81	39.4	0.63	2.79
26	33.4	0.72	2.47	54	48.3	0.58	2.48	82	37.8	0.30	1.79
27	35.2	0.90	3.47	55	36.1	0.22	1.41				
28	45.4	0.13	1.17	56	36.1	0.38	1.60				

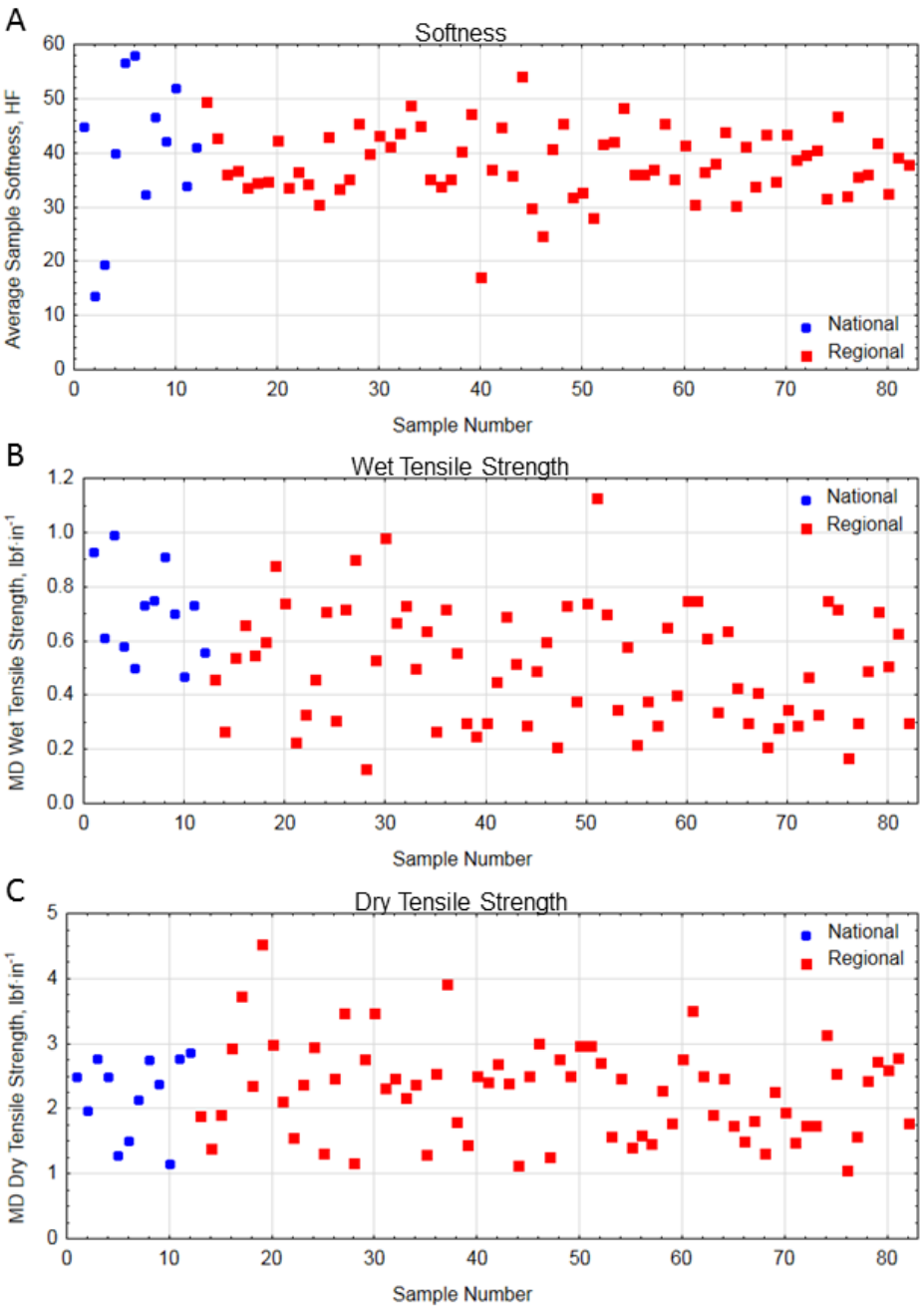

Figure A1: Arithmetic means for all samples for the three primary properties we measured in this study. (A) Softness. (B) MD wet tensile strength. (C) MD dry tensile strength.

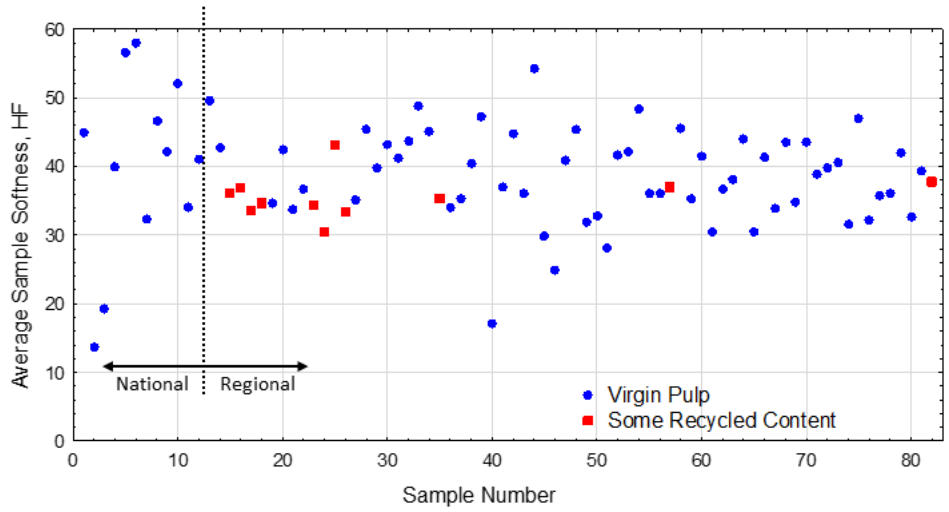

Figure A2: Mean softness for all samples, segregated by claims of inclusion of post-consumer recycled material versus virgin pulp.

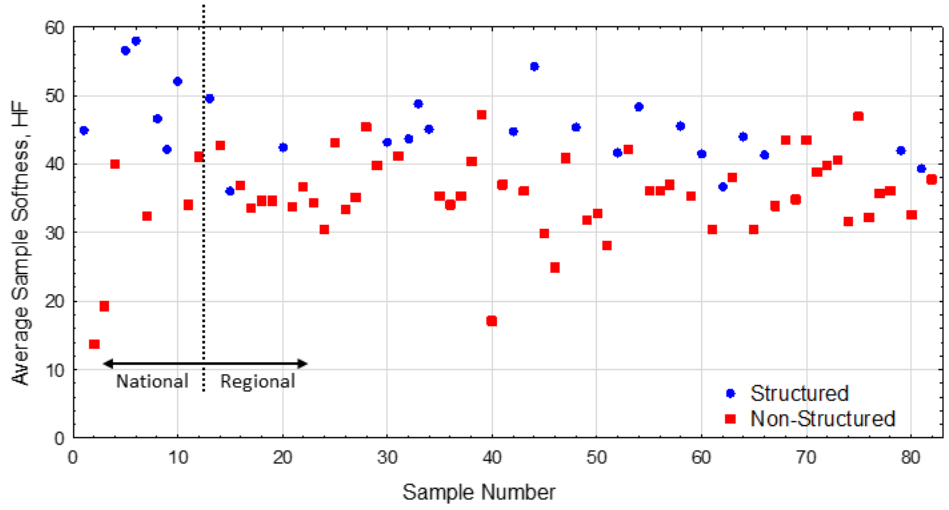

Figure A3: Mean softness for all samples, segregated by structured sheet products versus conventional wet press products.

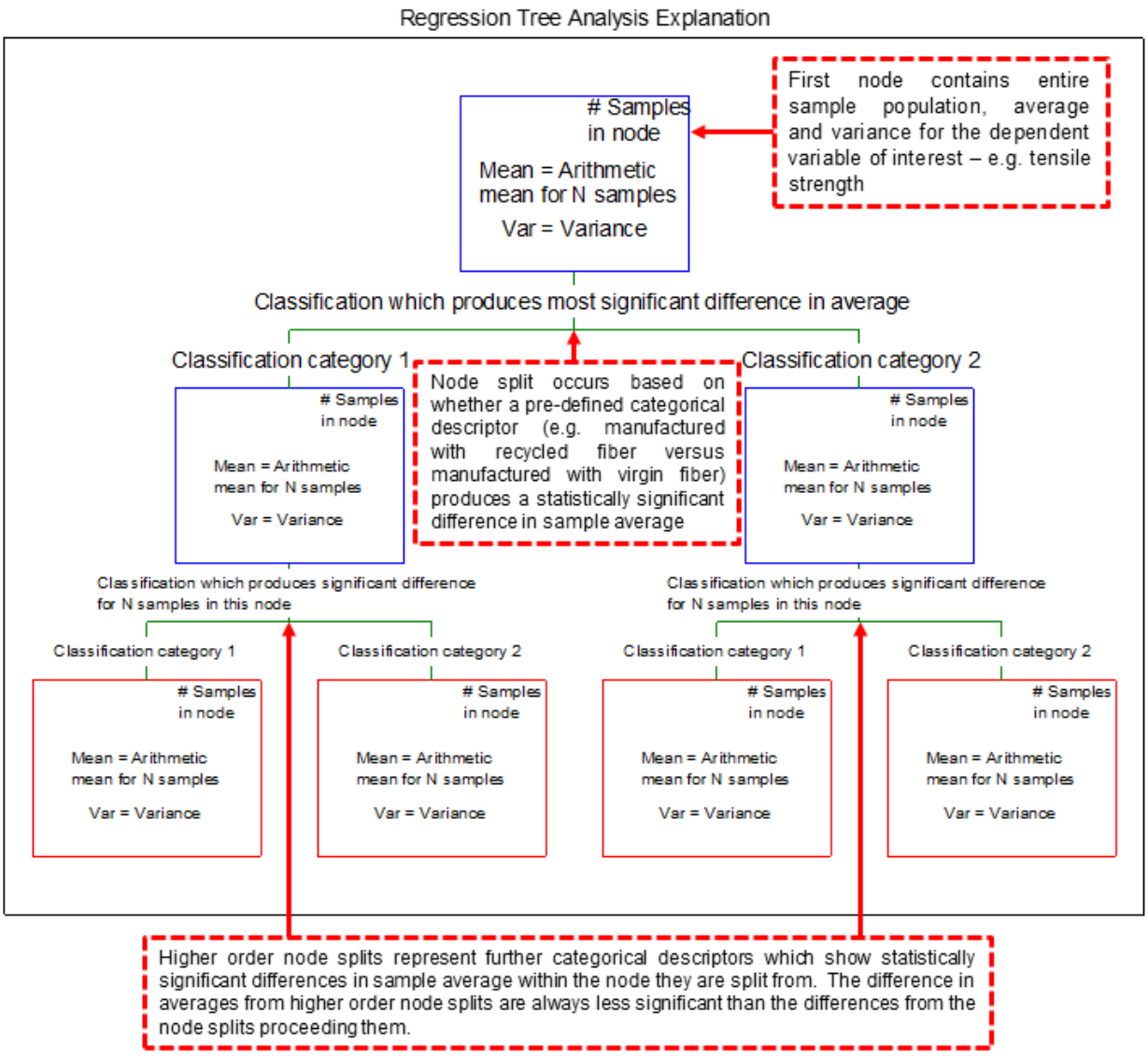

Figure A4: Schematic explaining how regression tree graphs are constructed to aid the reader in the interpretation of the regression trees presented in the body of the text.

Strong Feelings for Softness

A Comparative Study of US Towel Production

Gary Shelp

Georgia-Pacific Chemicals LLC

Thursday, May 18, 2017

Introduction

- Key differentiator in tissue and towel market: *Softness*
  - Goal: broad survey of softness and strength of at-home towel products
- Objective softness measurements: Emtec® Tissue Softness Analyzer
  - How/what does it measure
- Classifying samples: National vs regional; structured vs non-structure; recycled fiber claims vs no recycled-fiber claims
- How does softness and strength correlate to these classifications
- How does softness and strength correlate to each other
- Summary and conclusions

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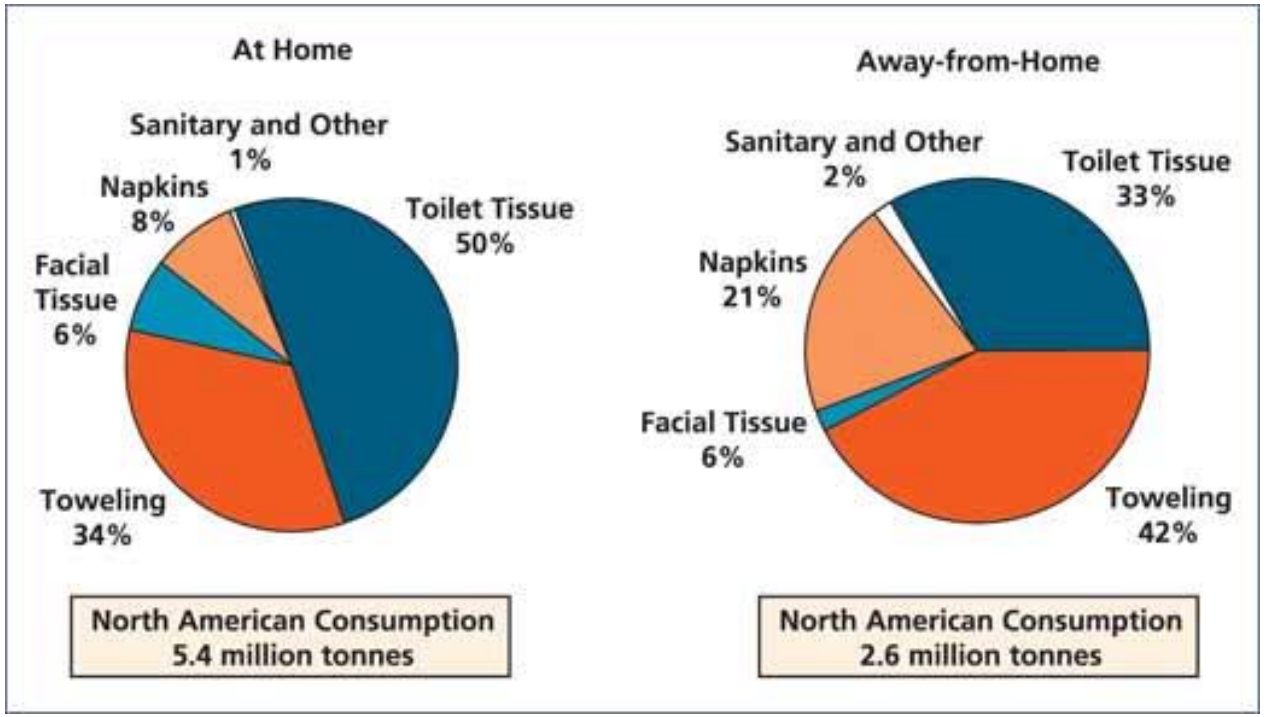
Introduction



Brad Kalil, Director of Tissue (October 2008). “Tissue market continues to grow” Pulp & Paper Int'l Digital Edition. RISI. Retrieved 2016-1-12

URL: http://legacy.risiinfo.com/magazines/pulp-paper/magazine/october/2008/PPMagOctober-Tissue-market-continues-to-grow.html

- North America top consumer of paper towels worldwide
- Towel softness often promoted as a key selling point
- What is softness?
- How is it measured?
- Knowledge gap as to where current products stand regarding towel softness

Emtec® Tissue Softness Analyzer

Blades

Sample clamp

Sample stage

Vibration sensor

- Blades are brought into contact with sample surface (100 mN force), spin for ~1.5 s, resulting sound is recorded/analyzed
  - Structural details and intrinsic fiber softness: $TS750$ and $TS7$
- Sample surface is then loaded/ unloaded/ re-loaded by blades
  - Mechanical properties of the sheet D, E, H, P
- Overall "handfeel" (HF) calculated from these 7 values plus caliper, grammage, and plies

$$HF \equiv f(TS7, TS750, D, E, H, P, caliper, BW, \#plies)$$

- *HF, higher values = softer tissue*

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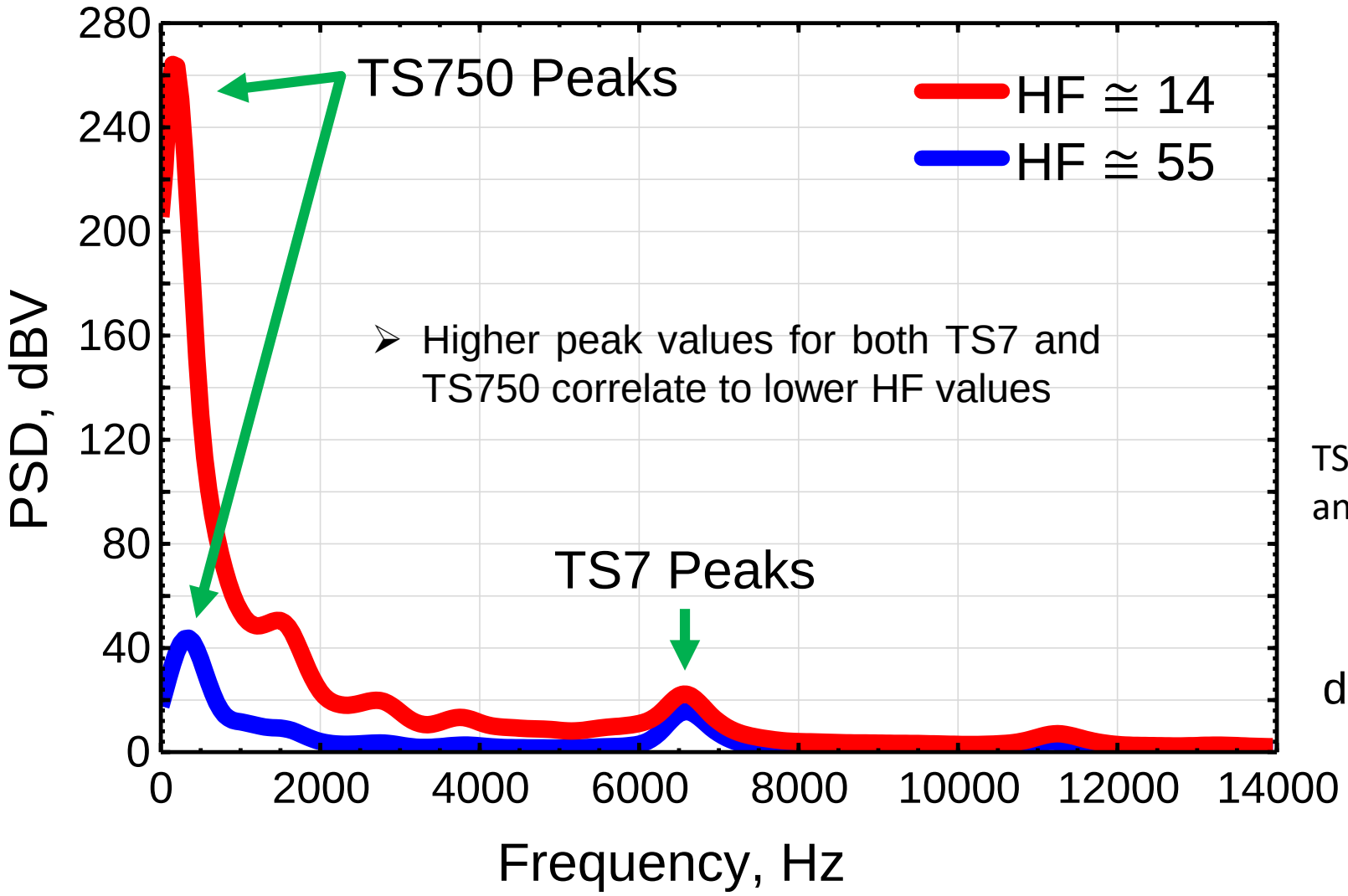
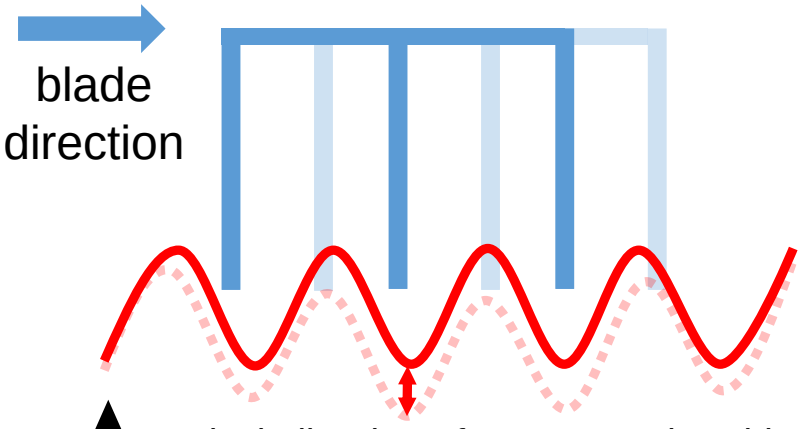
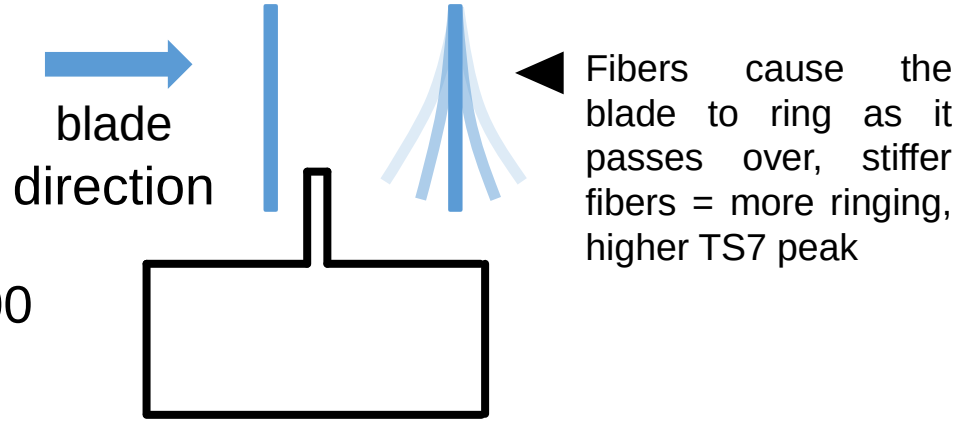
TS7 and TS750 Determined from Emtec® TSA



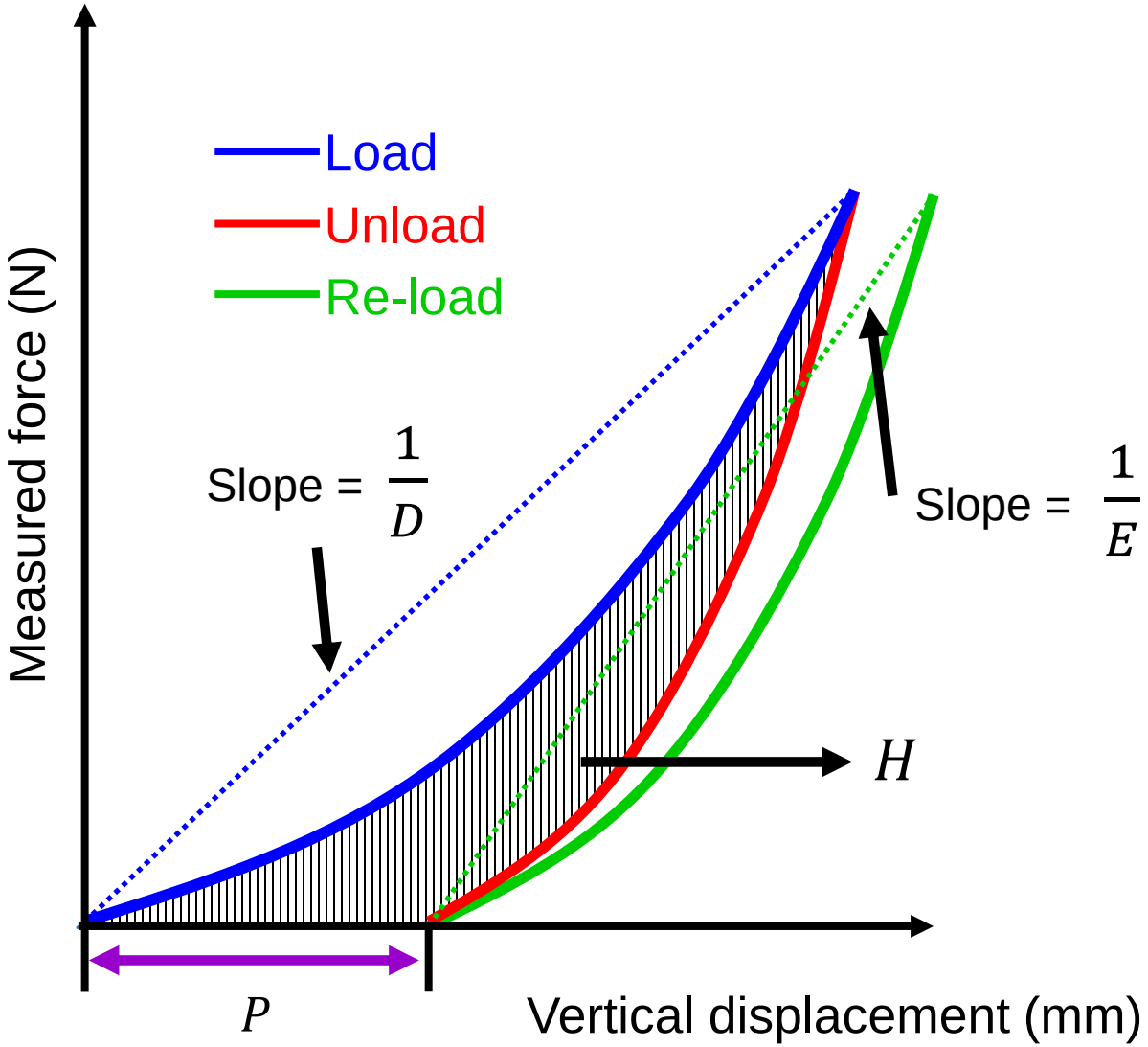
TS750 correlated to overall sheet structure

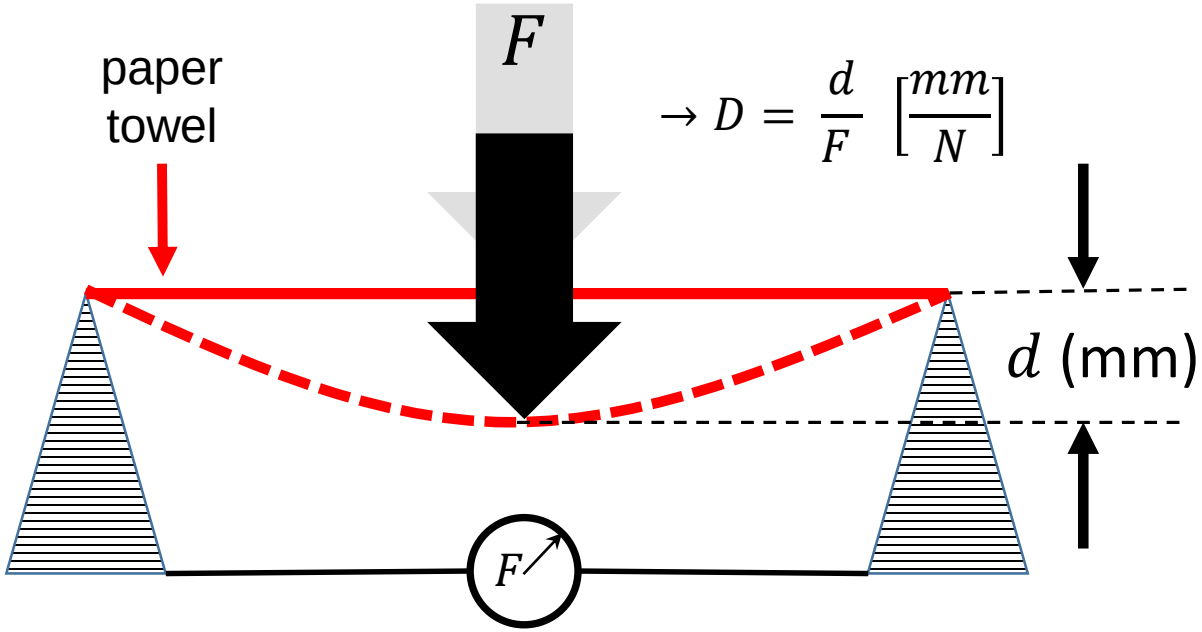


TS7 correlated more to intrinsic fiber flexibility and compliance



Mechanical Properties Considered by Emtec® TSA





- D – compliance of the sheet during initial loading (how far the blades push the sheet downward to produce a certain force)
- P – difference in vertical position of the blade after unloading to starting point force
- E – compliance of the sheet during second loading
- H – area bound by initial loading and unloading curves. Measure of the work of “plastic” deformation

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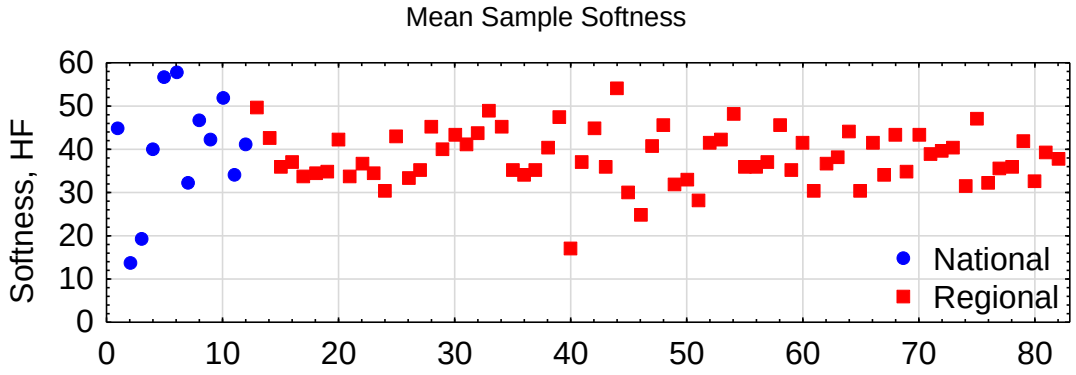
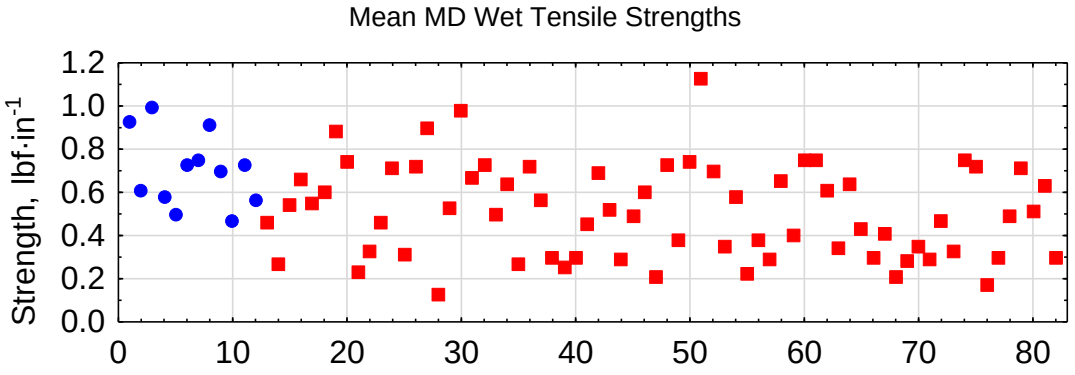
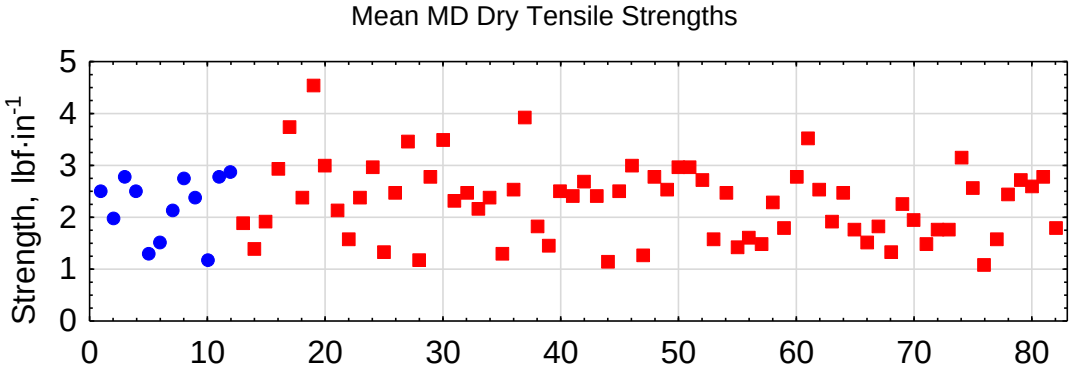
Raw Data – Softness, Wet Tensile Strength, and Dry Tensile Strength







Softness measurements:

- Caliper and grammage averaged from 16 sheets
- For each softness data point – 8 sheets measured on top, 8 sheets measured on bottom, mean for all 16 measurements presented

Wet Tensile Strength

- Test strips conditioned in CTH; soaked in DI water 3 min.; pulled to failure
- Mean from 16 measurements
- MD wet tensile strength determined using TAPPI T 456 om-10

Dry Tensile Strength:

- Test strips conditioned in CTH; pulled until failure
- Mean from 16 measurements
- MD dry tensile strength determined using TAPPI T 494 om-01

Classifying Samples

➢ *Correlation of softness, wet strength, dry strength with following classifications (categorical factors):*

National or regional brands

Structured or non-structured

Virgin fiber or claims of recycled content

National:

- wide availability across the country
- prominent multi-media advertising campaigns

Regional:

- private-label and store brands
- limited geographic availability

Structured:

- sheet produced in such a way that bulk *does not* rely primarily on dry end crepe and embossing

Non-structured:

- sheet bulk created through dry end creping and embossing (e.g. CWP machines)

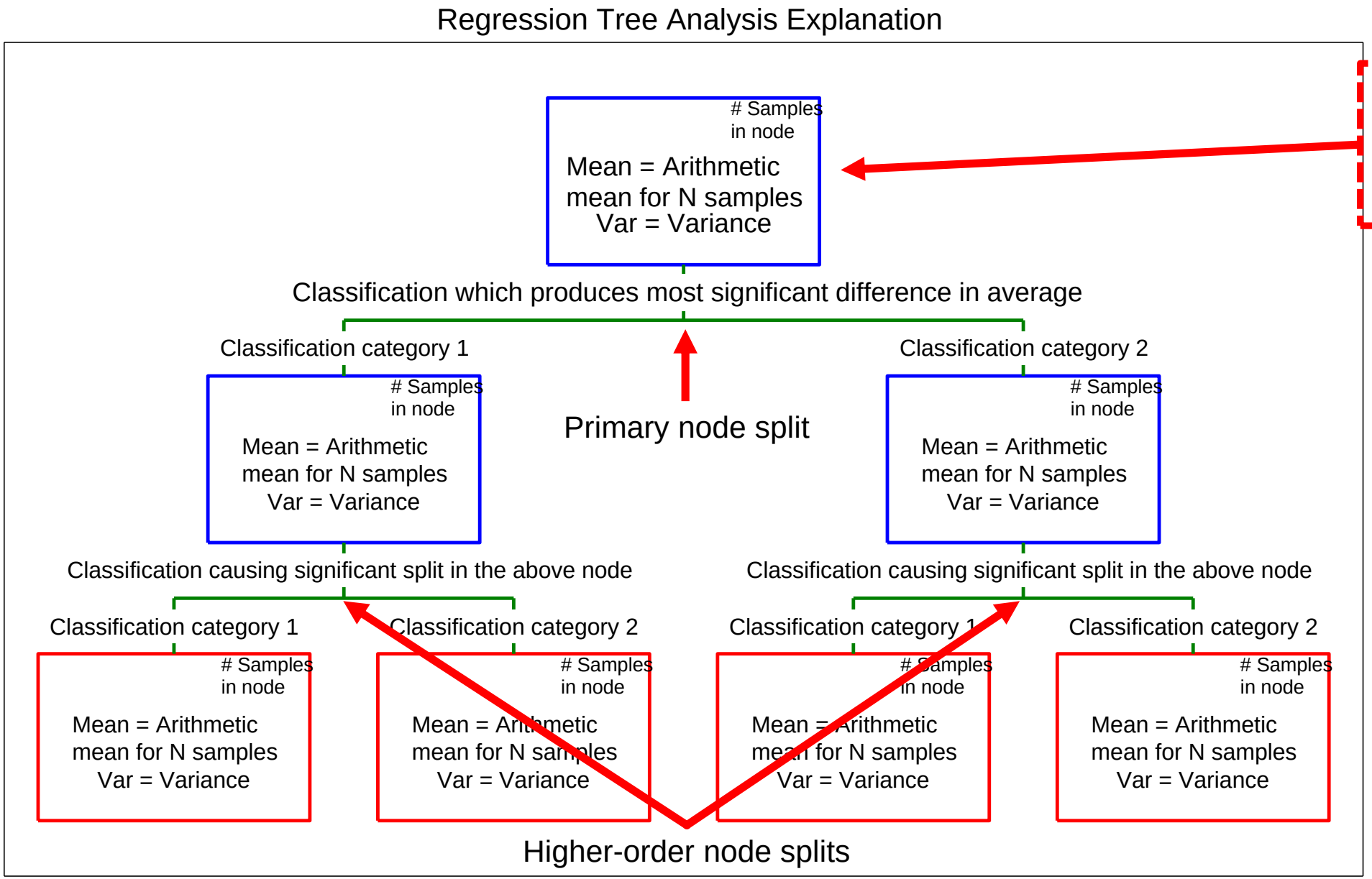
Recycled claims:

- packaging prominently displayed claims of recycled content inclusion

Virgin:

- packaging did not have any claims of recycled content
- major assumption – we recognize that no claim does not necessarily mean virgin fiber only

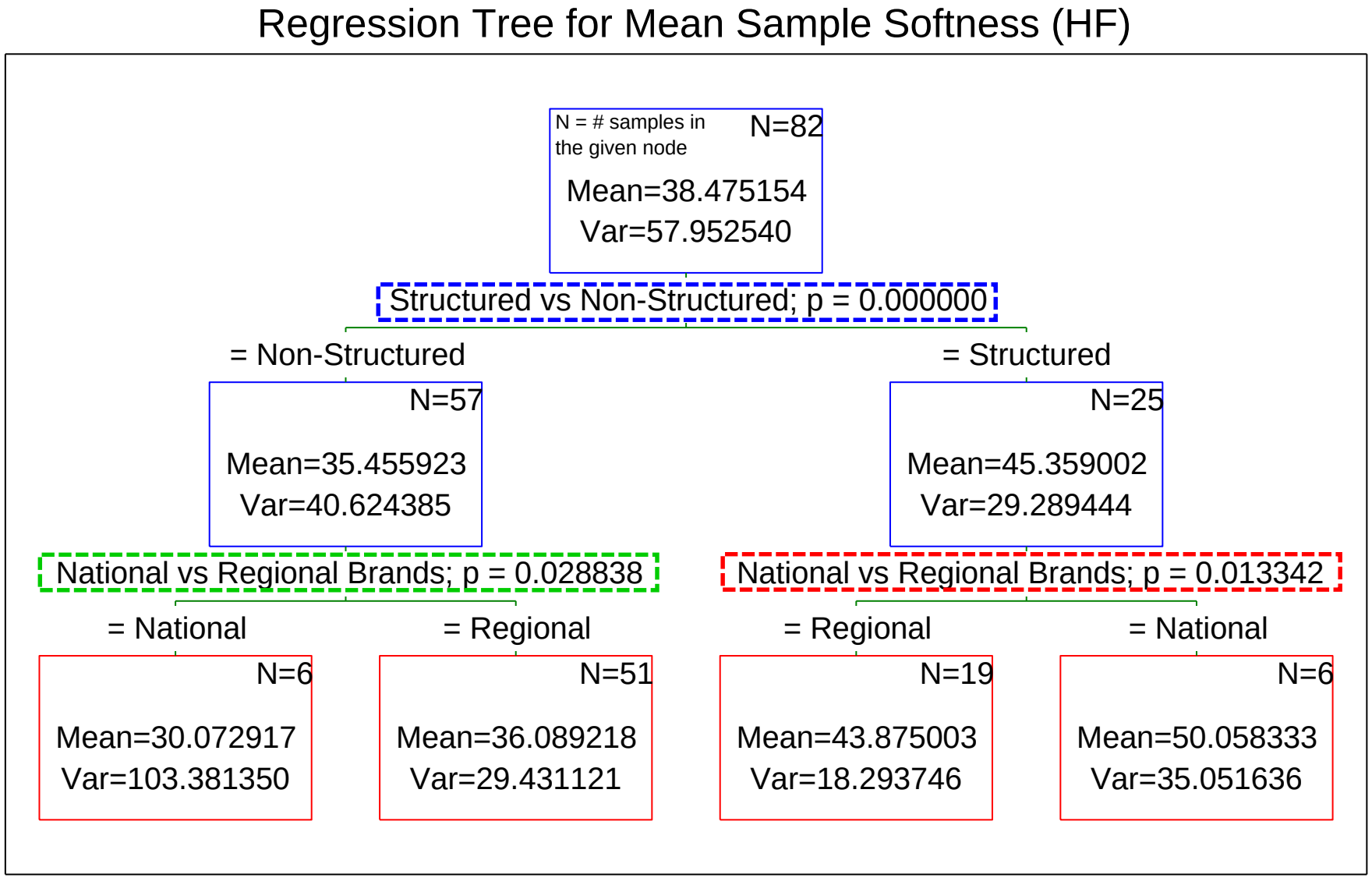
Interpreting Regression Trees

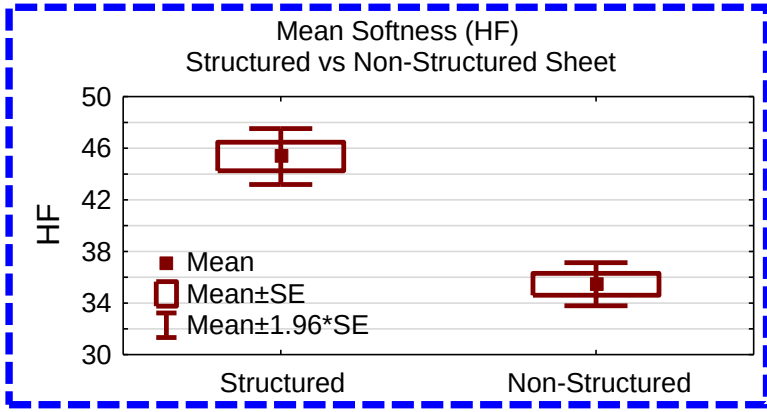


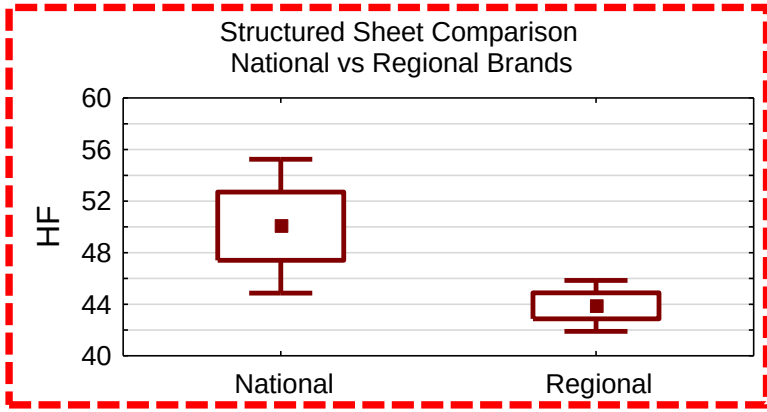
First node: mean and variance for variable of interest for entire sample population – e.g. tensile strength

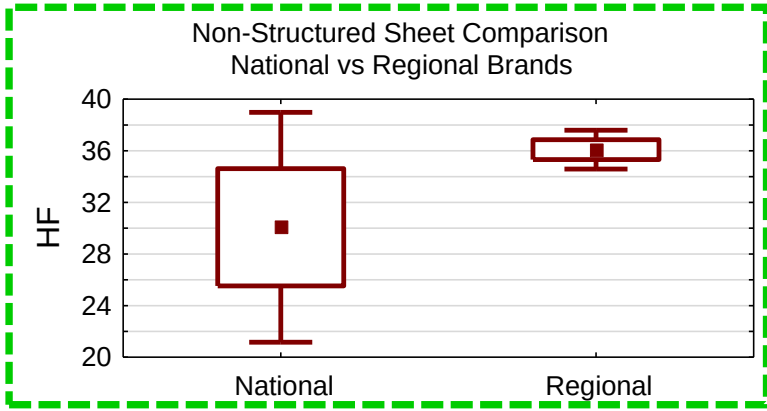
- Node splits based on categorical factor which causes significant difference in variable mean in preceding node (located above the split)
- Splits further up the chart represent higher degree of statistical significance (e.g. primary node split is more statistically significant than higher-order splits below it)
- Box-whisker plots illustrate this

Classification Breakdown: Sample Softness

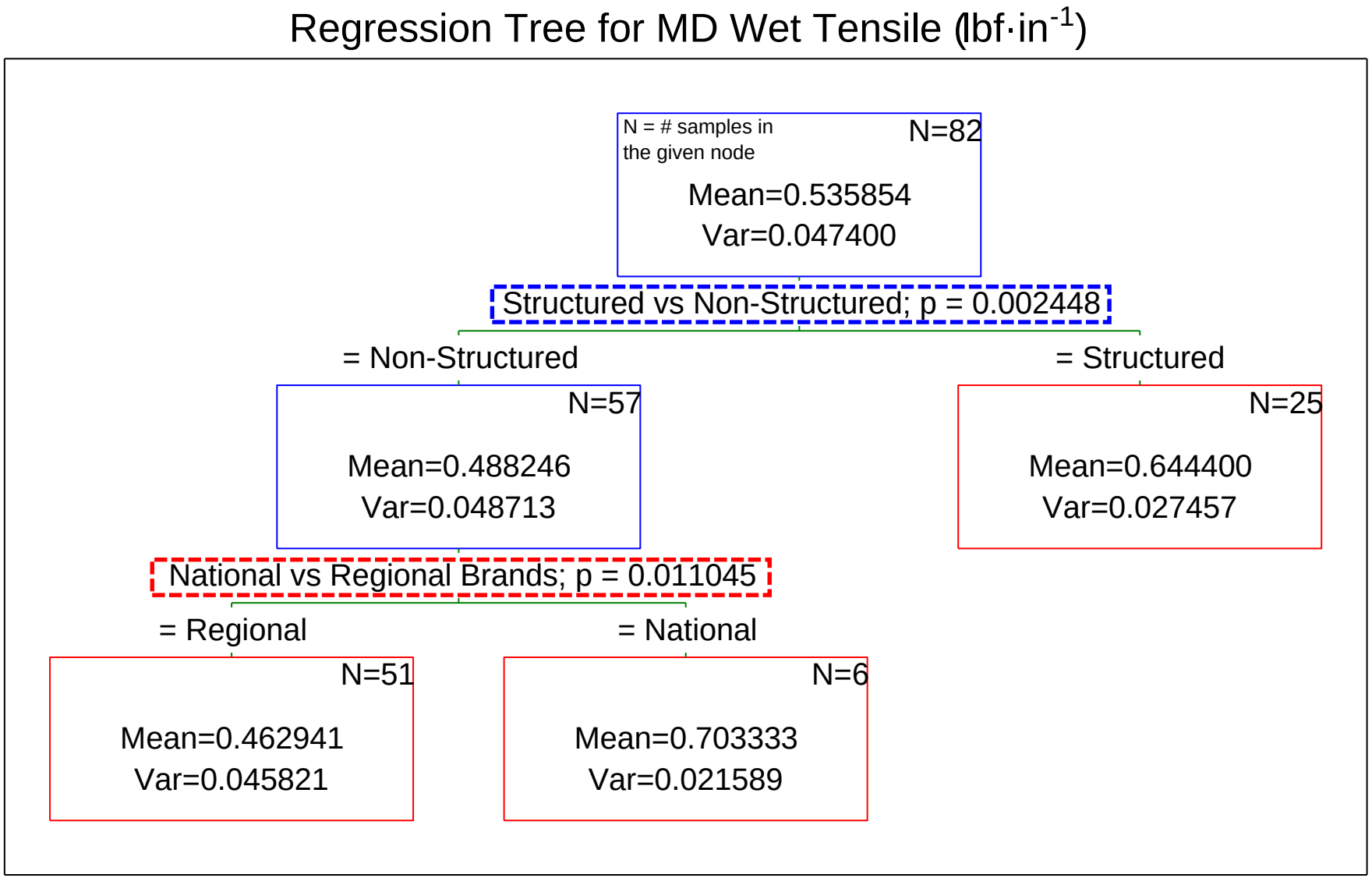


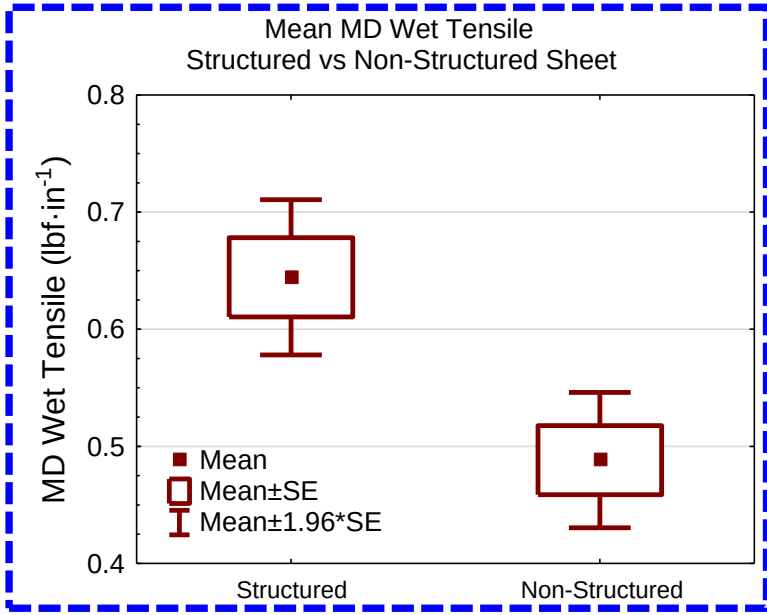


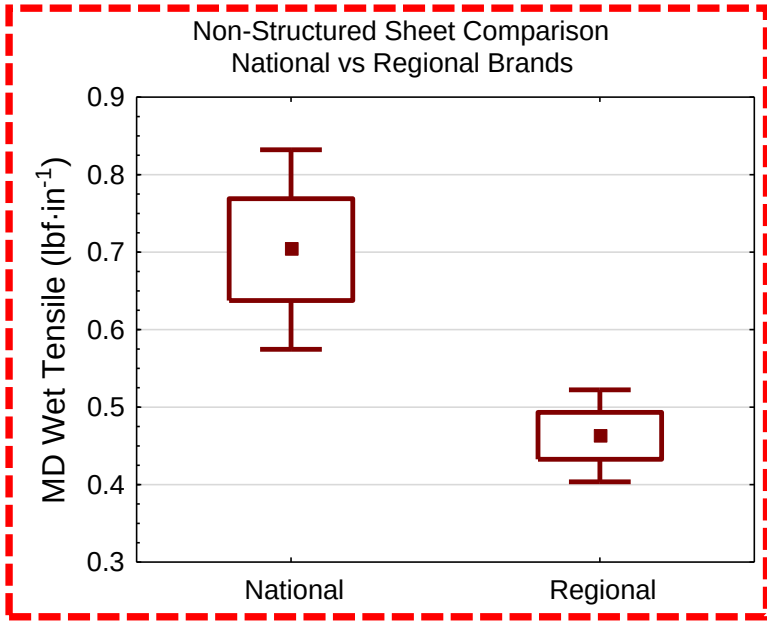




Classification Breakdown: MD Wet Tensile Strength

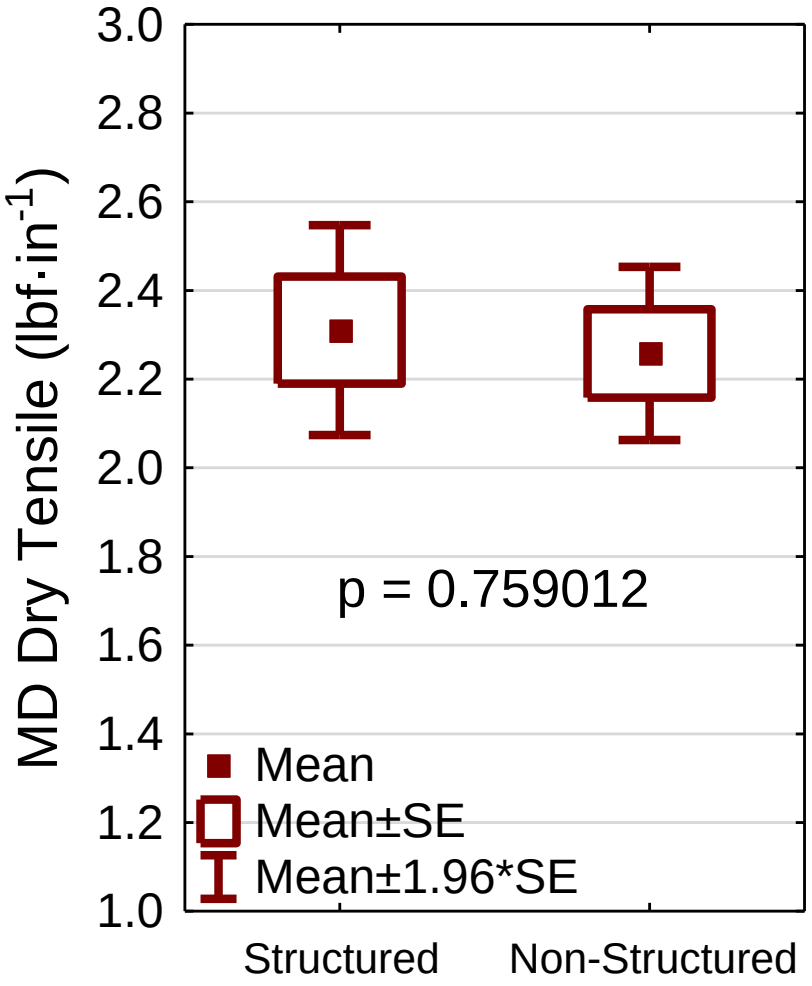


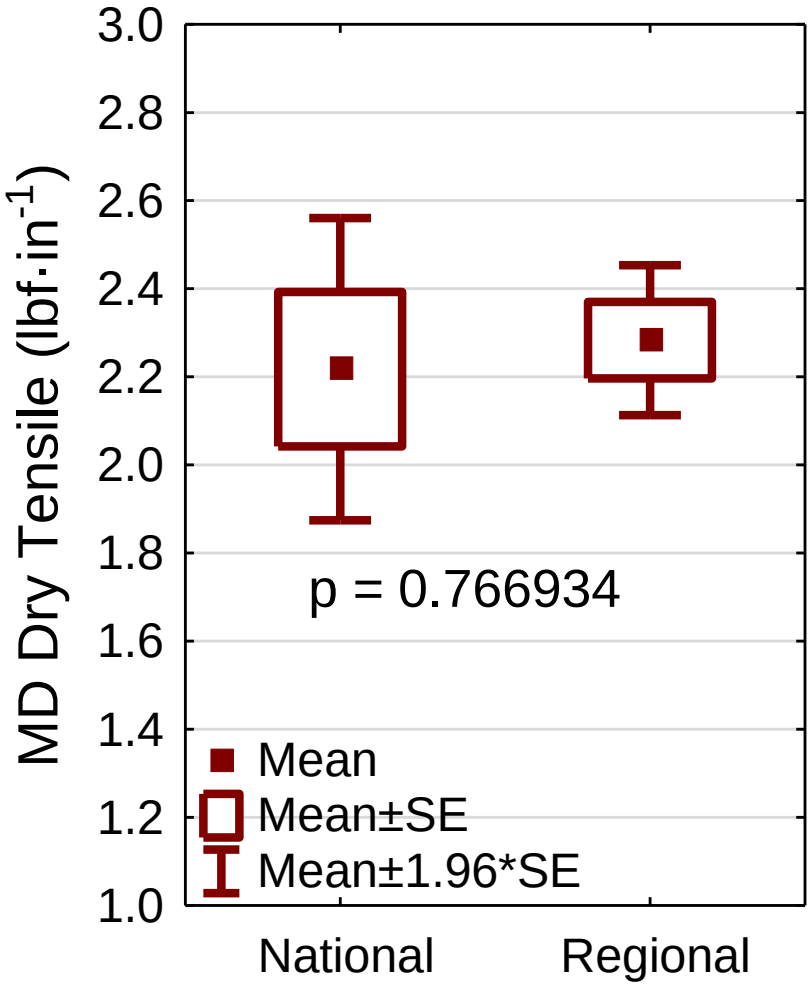


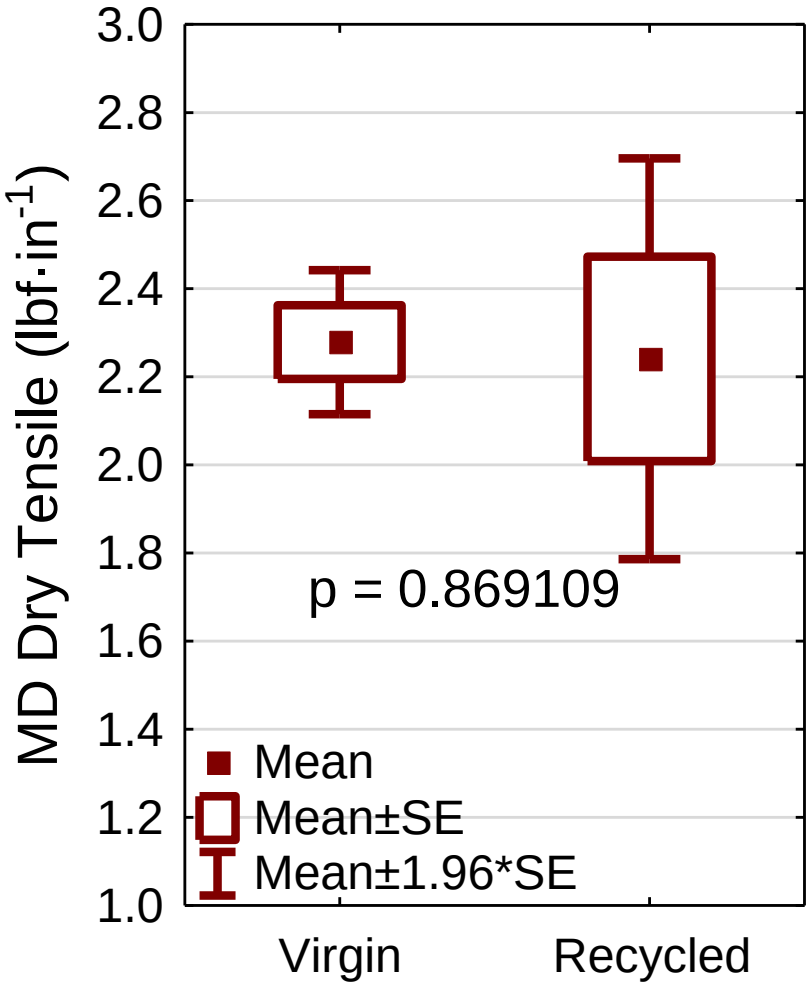


Classification Breakdown: MD Dry Tensile Strength

No classification produced statistically significant differences in MD dry tensile strengths

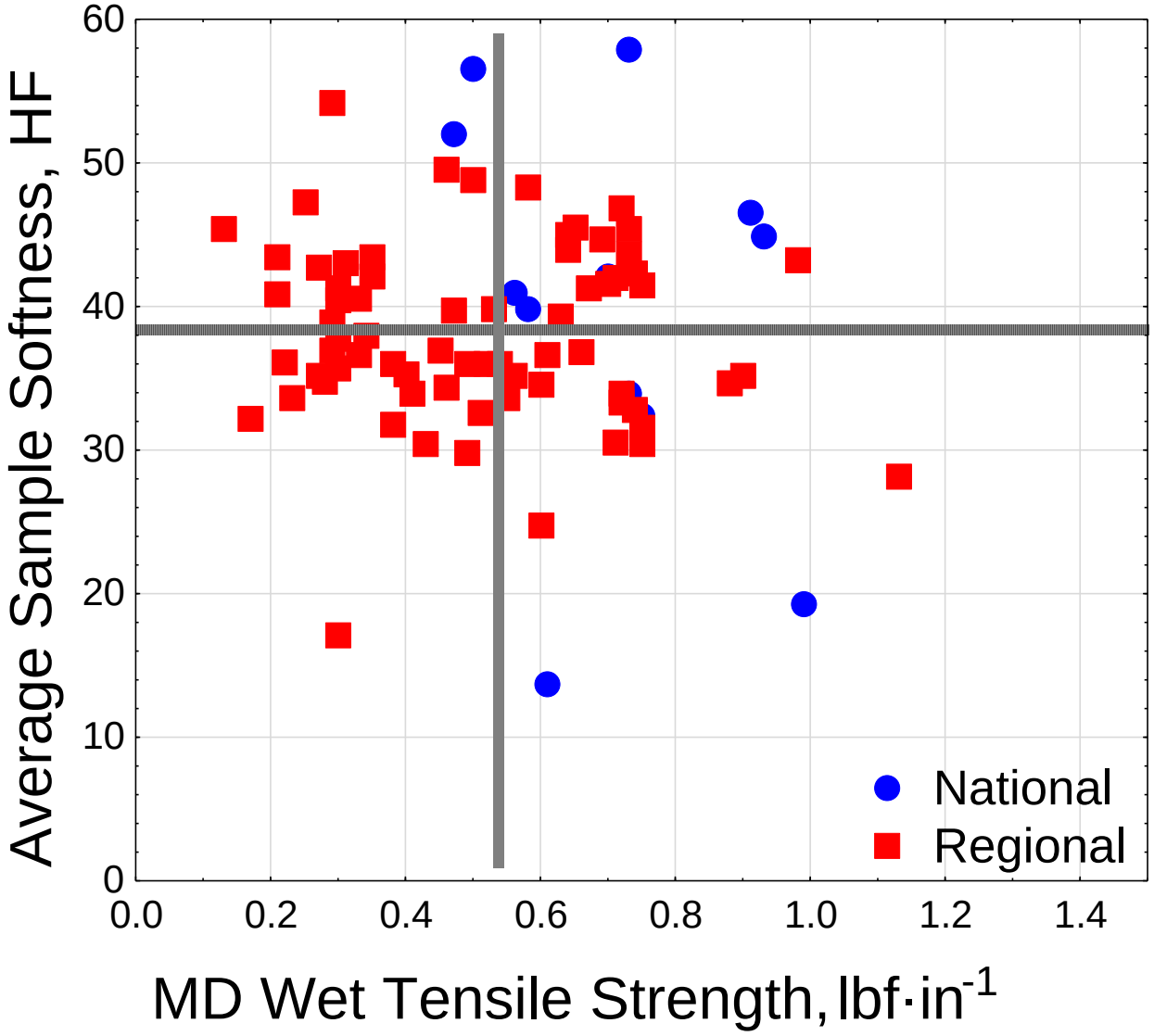


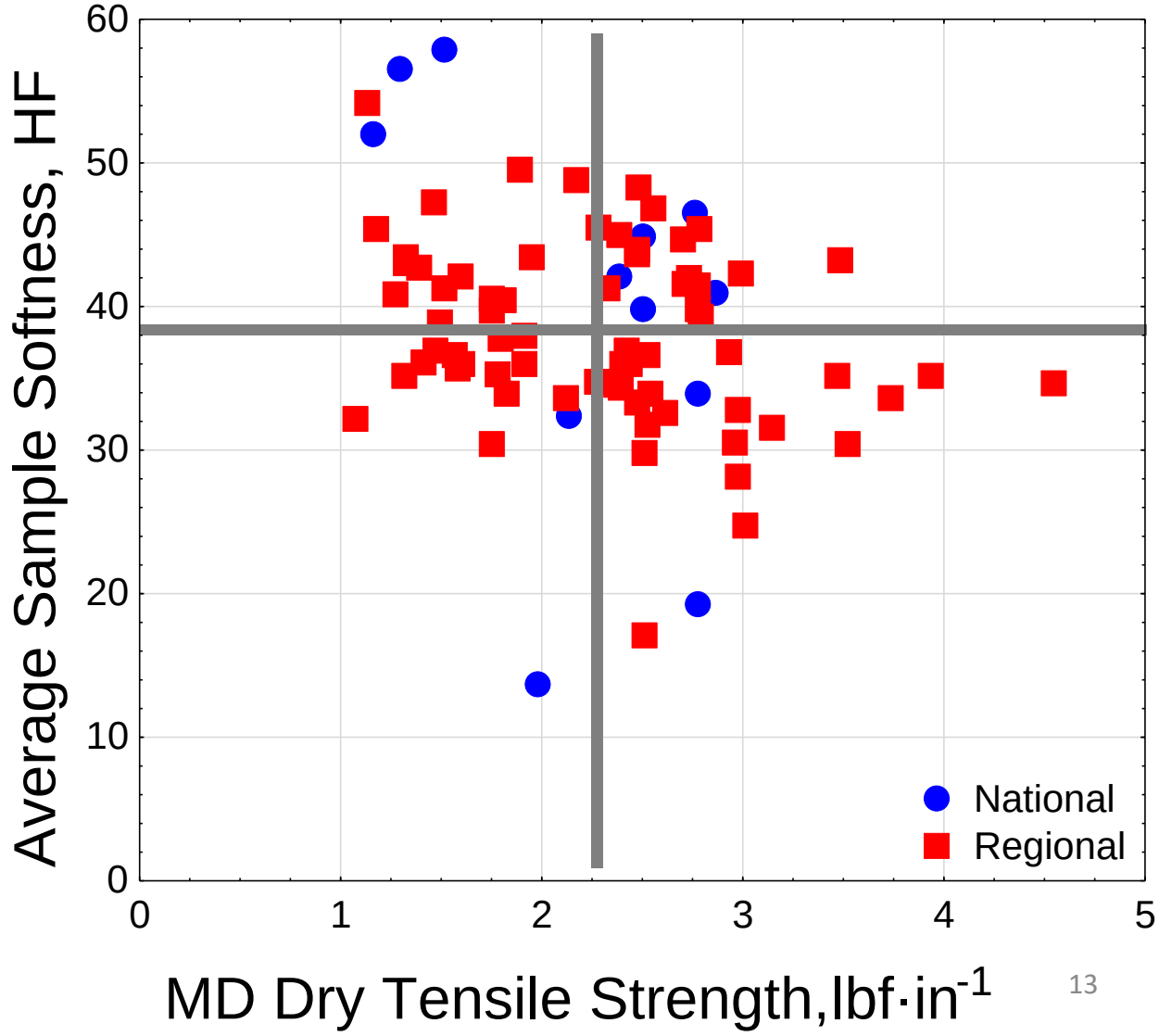




Strength versus Softness

➢ *No distinctive correlation between wet or dry tensile strength and softness*





Conclusions

- ***Contrary to conventional wisdom, correlation between strength and softness was not as well defined as expected***
- ***No one towel had simultaneously the highest softness and highest strength***
- Structured vs non-structured classification produced the most significant difference in softness and wet tensile strength, with structured sheet towels exhibiting better performance in both
- National vs regional classification produced the next most significant difference in softness and MD wet tensile strengths
- No statistically significant difference observed between virgin and recycled fiber content claims for any property measured here.
- Emtec® TSA represents a commercially available option for objective towel softness testing, but has some of its own drawbacks

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