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Pine AF850T/TD Deformation Rate & Sprocket Arrangement

Executive Summary

Pine slowed the specimen deformation rate of the Pine AF850 Test Press by installing the same size sprockets on the motor and the jack to achieve a 1:1 ratio between the motor and the jack because it was found not to comply with the specimen deformation rate of 50 ± 2 mm/minute specified by ASTM D8225-19. NCAT conducted testing on 9 mixes using one test press with the Current Sprocket Arrangement (a 16-tooth on the motor and a 15-tooth on the jack for a 1.0667 Ratio) and the same machine with a 1:1 Ratio Sprocket Arrangement. Analysis of the data led to the following conclusions.

1. Specimen Deformation Rate
    a. The Current Sprocket Arrangement runs at an average of 54.56 mm/min with a standard deviation of ± 0.23 mm/min. The range is 53.98 to 55.49 mm/min.
    b. The 1:1 Ratio Sprocket Arrangement runs at an average of 51.11 mm/min with a standard deviation of ± 0.21 mm/min. The range is 50.66 to 51.56 mm/min.
2. CT Index
    a. Considering each mix individually, there is no statistical difference in the CT Indices generated by the different sprocket arrangements.
    b. Considering differences between the average values of the sprocket arrangements for all 9 mixes together, one can state with 95% confidence that the 1:1 Ratio Sprocket Arrangement generated a CT Index that was about 4.4 units higher than the same machine with the Current Sprocket Arrangement.
    c. The difference of 4.4 units is lost in the variability of the data for the individual mixes.
3. Peak Stability
    a. Considering each mix individually,
        i. Mixes A, B, D, F, G, H, and I show a lower average Peak Stability for the 1:1 Ratio Arrangement.
        ii. Mixes C and E show an increase in average Peak Stability for the 1:1 Ratio Arrangement.
        iii. Only the differences in Mixes F and I are statistically significant.
    b. Considering the differences between the average Peak Stability values for all 9 mixes together, with 95% confidence, one can state that the average Peak Stability is about 2.7% lower for the 1:1 Ratio Sprocket Arrangement when compared to the Current Arrangement.

The Problem

The Pine AF850 Test Press does not comply with ASTM D8225's required specimen deformation rate of 50 ± 2 mm/minute, as previously communicated.

A Solution

The Pine AF850T Test Press was designed and built with a 16-tooth sprocket on the motor and a 15-tooth sprocket on the jack. This 1:1.0667 Ratio Sprocket Arrangement is referred to in the remainder of this document as the Current Arrangement. Pine slowed the specimen deformation rate of the machine by replacing the 15-tooth sprocket on the jack with a 16-tooth sprocket to achieve a 1:1 Ratio Arrangement.

Testing of the Solution

NCAT completed several experiments from which data was used for this analysis: one with 7 mixes (A – G) including 8 specimens per mix, and two with one mix (H and I) including 5 and 4 specimens respectively. Pine AF850T serial number 534 upgraded with a digital recorder kit was used. This document provides an analysis of the data from NCAT's testing.

Five questions will be addressed.

1. How did the 1:1 Ratio Arrangement affect the Specimen Deformation Rate?
2. How did the 1:1 Ratio Arrangement affect the CT Index?
3. How did the 1:1 Ratio Arrangement affect the Peak Stability?
4. What does Pine recommend with respect to the sprocket arrangements?
5. What does Pine recommend with respect to paper vs. digital recorder configurations?

How did the 1:1 Ratio Arrangement affect the Specimen Deformation Rate?

The goal of the modification was to bring the Specimen Deformation Rate into conformance with ASTM D8225, 50 ± 2 mm/min.

The specimen deformation rate is the slope of the best-fit line of the time versus displacement data generated by the machine (Figure 1) according to Dr. Fujie Zhou, technical contact for ASTM D8225.

Table 1 summarizes the Specimen Deformation Rate for the Current and 1:1 Ratio Arrangements. Outlier data were removed for the analysis in accordance with ASTM E178. The range for the Current Arrangement is 53.98 to 55.49 mm/min. The range for the 1:1 Ratio Arrangement is 50.66 to 51.56 mm/min. The overall average Specimen Deformation Rate for the Current Arrangement was 54.56 mm/min compared to 51.09 mm/min for the 1:1 Ratio Arrangement. Detailed data is provided in Table 4 at the end of this document.

All data for the 1:1 Ratio Arrangement fell within the allowable tolerance in ASTM D8225 of 50 ± 2 mm/min.

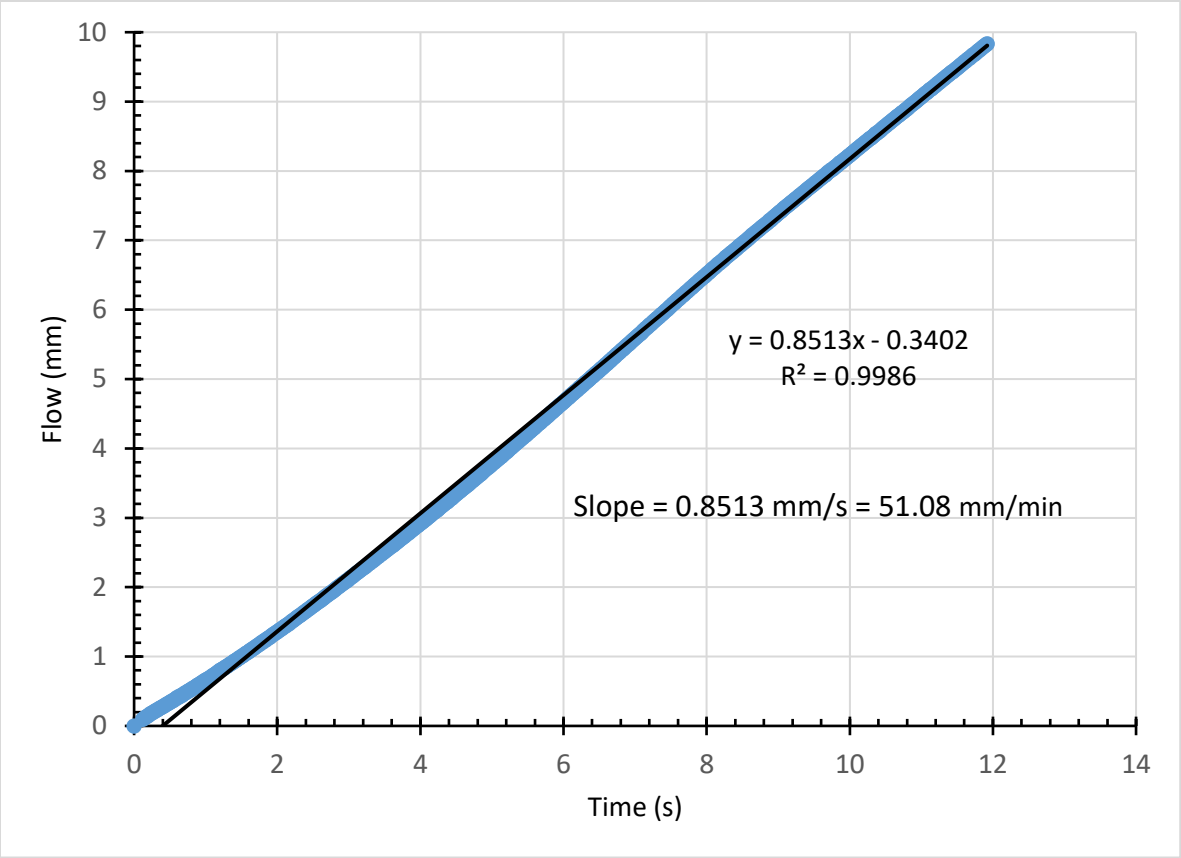

Figure 1: Time vs. Displacement.

Table 1: Summary of Specimen Deformation Rate Data.

Mix	Specimen Deformation Rate (mm/min)			
	Current Arrangement		1:1 Ratio Arrangement	
	Average	Std. Deviation	Average	Std. Deviation
A	54.52*	± 0.12	50.97	± 0.20
B	54.74	± 0.15	51.27	± 0.13
C	54.53	± 0.09	51.07	± 0.20
D	54.60*	± 0.03	51.13	± 0.12
E	54.32	± 0.16	50.93	± 0.16
F	54.67	± 0.17	51.17	± 0.15
G	54.53	± 0.22	51.09	± 0.13
H	55.05+	± 0.38	51.54	± 0.03
I	54.43	± 0.11	50.88	± 0.15
All	54.56	± 0.23	51.11	± 0.21

* One outlier in this set of 8 data points was removed in the statistical analysis per ASTM E178.
+ One outlier in this set was removed in the statistical analysis of all the data per ASTM E178.

How did the 1:1 Ratio Arrangement affect the CT Index?

A summary of the CT Index results are shown in Table 2 and Figure 2. Outliers as determined using ASTM E178 were removed from the data for this analysis. While the average CT Index shows an increasing trend from the Current to the 1:1 Ratio Arrangement when comparing the average values by mix, none of the differences are statistically significant (determination of statistical significance is explained below). However, a t-test analysis presented below of the average difference between sprocket arrangements by mix indicates the difference is statistically significant with 95% confidence. Detailed data is provided in Table 5 at the end of this document.

Table 2: Summary of CT Index.

Mix	CT Index				
	Current Arrangement		1:1 Ratio Arrangement		Difference in Averages
	Average	Std. Deviation	Average	Std. Deviation	Current – 1:1 Ratio Arrangement
A	48.7	± 8.5	54.3*	± 3.6	-5.6
B	40.4	± 5.9	40.9*	± 2.9	-0.6
C	50.6*	± 8.7	55.2	± 11.0	-4.6
D	55.5	± 7.3	56.8	± 6.9	-1.3
E	70.3	± 13.8	63.6*	± 8.5	6.7
F	59.0	± 8.6	68.8	± 8.7	-9.8
G	79.8*	± 3.8	85.4*	± 7.8	-5.6
H	53.0	± 19.9	61.3	± 14.8	-8.3
I	103.1	± 22.2	113.8	± 24.8	-10.7
				Average	-4.41
				Standard Deviation	± 5.41

* One outlier in this set of data points was removed in the statistical analysis.

Statistically significant difference by mix is determined in the following manner. Consider Mix A in Figure 3.

- The bar represents the average CT Index value of the specimens included in the data set. Each bar represents 8 specimens except where an outlier was identified. Table 2 indicates that Mix A for the 1:1 Ratio Arrangement had one outlier. Therefore, the statistics are based on data from 7 specimens instead of 8. For Mix A, the average for the 1:1 Ratio Arrangement of 54.3 is greater than the average for the Current Arrangement of 48.7.
- The line on the top end of each bar represents the standard deviation of the data included in the calculation of the average, which represents the distribution of the data around the average value. If the standard deviation bars for the data being compared overlap, the difference between the averages represented by the bars is not statistically significant. The Current Arrangement for Mix A covers a range of 40.2 to 57.2 (48.7 ± 8.5). The 1:1 Ratio Arrangement for Mix A covers a range of 50.7 to 57.9 (54.3 ± 3.6). The ranges for the two sprocket arrangements, 40.2 to 57.2 and 50.7 to 57.9 overlap therefore the difference between the average values of 48.7 and 54.3 is determined to not be statistically significant.

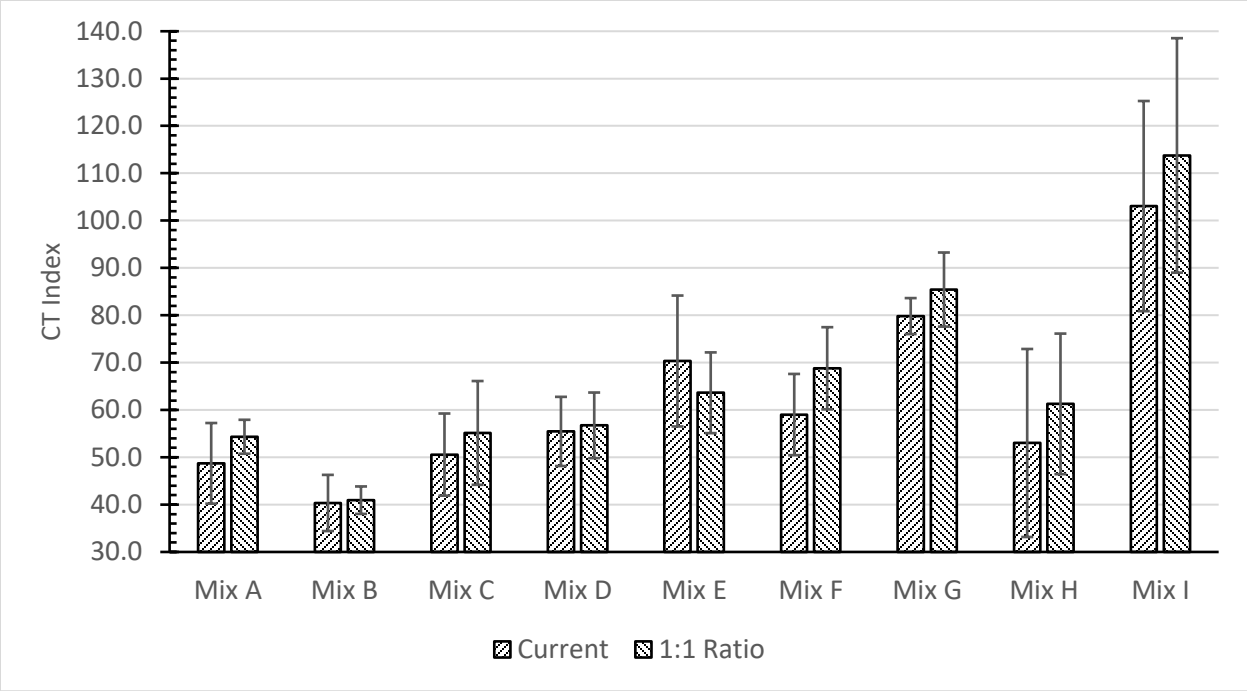

Figure 2: CT Index Comparison by Mix Showing Average and Standard Deviation.

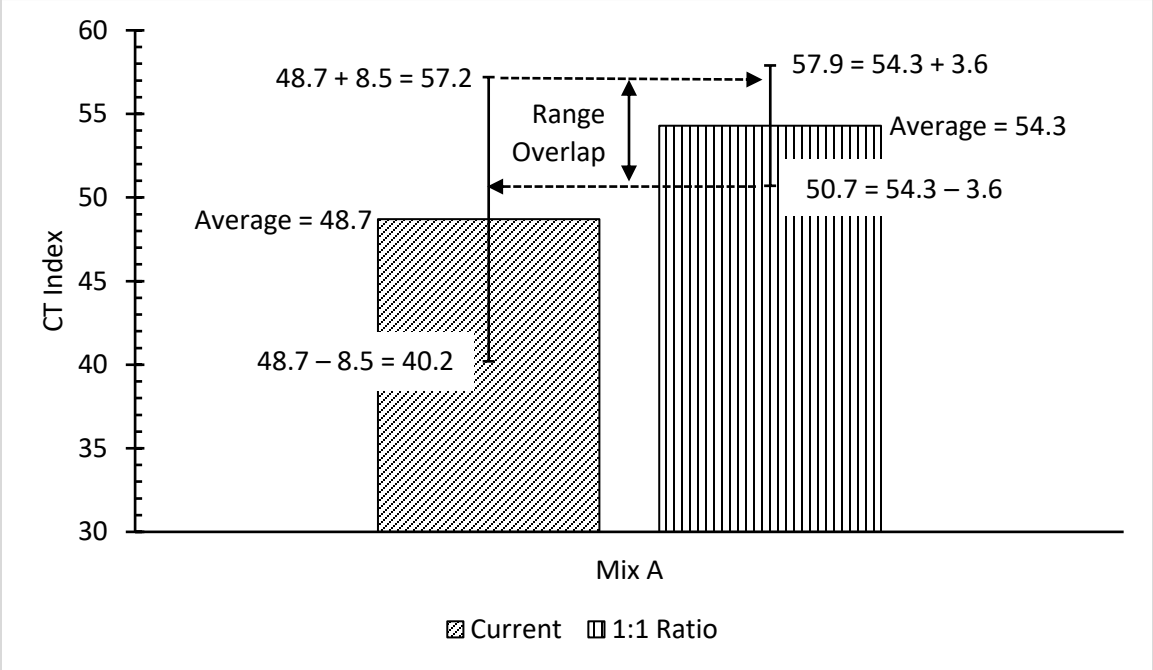

Figure 3: Analysis of Difference Between Sprocket Arrangement For Mix A.

Further considering the data comparison in Figure 2 for each of the mixes reveals that the average CT Index for the 1:1 Ratio Arrangement is higher than the Current Arrangement for all mixes except Mix E. Statistical analysis of the average CT Index values using the t-test explores the difference between systems (i.e., Current and 1:1 Ratio Arrangements). Figure 4 shows the average difference and the 95% confidence interval generated using the t-test. Because the confidence interval does not cross a CT Index value of zero, we can state with 95% confidence that the average CT Index is about 4.4 units higher for the 1:1 Ratio Arrangement than for the Current Arrangement.

Compare the average difference of 4.4 units between systems to the standard deviation for each mix in Table 2. Only 3 of the 18 data sets in Table 2 have a standard deviation less than 4.4 units. Therefore, one can conclude that while there is a bias between systems, it is lost in the variability of the test results.

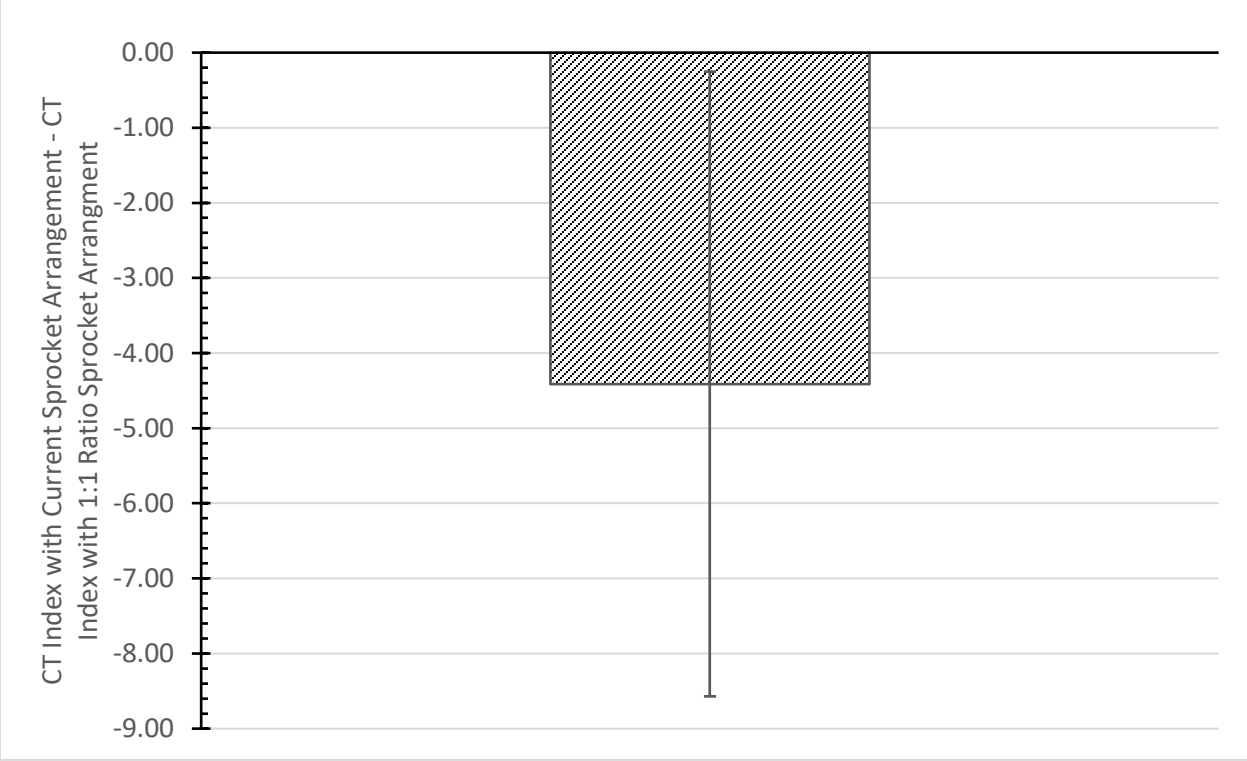

Figure 4: System Comparison.

How did the 1:1 Ratio Arrangement affect the Peak Stability?

Some users of the Pine AF850T use their machines for Marshall and TSR testing and have accumulated a significant amount of historical data on their mixes. If reducing the Specimen Deformation Rate reduces the Peak Stability, a machine with the 1:1 Ratio Arrangement will deliver different results than one has seen historically. If the peak stability is reduced by slowing the Specimen Deformation Rate, mixes that have just passed Marshall and TSR tests may fail.

A summary of the data is presented in Table 3 and Figure 5. Outlier data were removed for the analysis according to ASTM E178. Mixes A, B, D, F, G, H, and I show a lower average Peak Stability with the 1:1 Ratio Arrangement. Mixes C and E show an increase in average Peak Stability with the 1:1 Ratio Arrangement. Only the difference in Mixes F and I are statistically significant. However, a t-test analysis of the differences between sprocket arrangements by mix indicates that a statistically significant difference does exist with 95% confidence. Detailed data is provided in Table 6 at the end of this document.

Table 3: Summary of Peak Stability Data – Original Data Converted from kN to lb.

Mix	Peak Stability (lb)					
	Current Arrangement		1:1 Ratio Arrangement		Difference in Averages	
	Average	Std. Dev.	Average	Std. Dev.	Current – 1:1 Ratio Arrangement	% of Current
A	3,373*	± 77	3,331	± 72	42	1.26
B	3,795	± 135	3,657	± 77	138	3.61
C	3,771	± 125	3,879*	± 70	-108	-2.86
D	4,043	± 58	3,898	± 89	145	3.59
E	3,490*	± 46	3,502*	± 76	-12	-0.34
F	4,334*	± 60	4,122	± 107	212	4.90
G	4,723	± 131	4,489	± 122	234	4.95
H	5,968	± 236	5,741	± 230	227	3.80
I	4,416	± 168	4,184	± 7	232	5.26
				Average	123.4	2.69
				Standard Deviation	± 123.3	2.77

* One outlier in this set of data points was removed in the statistical analysis.

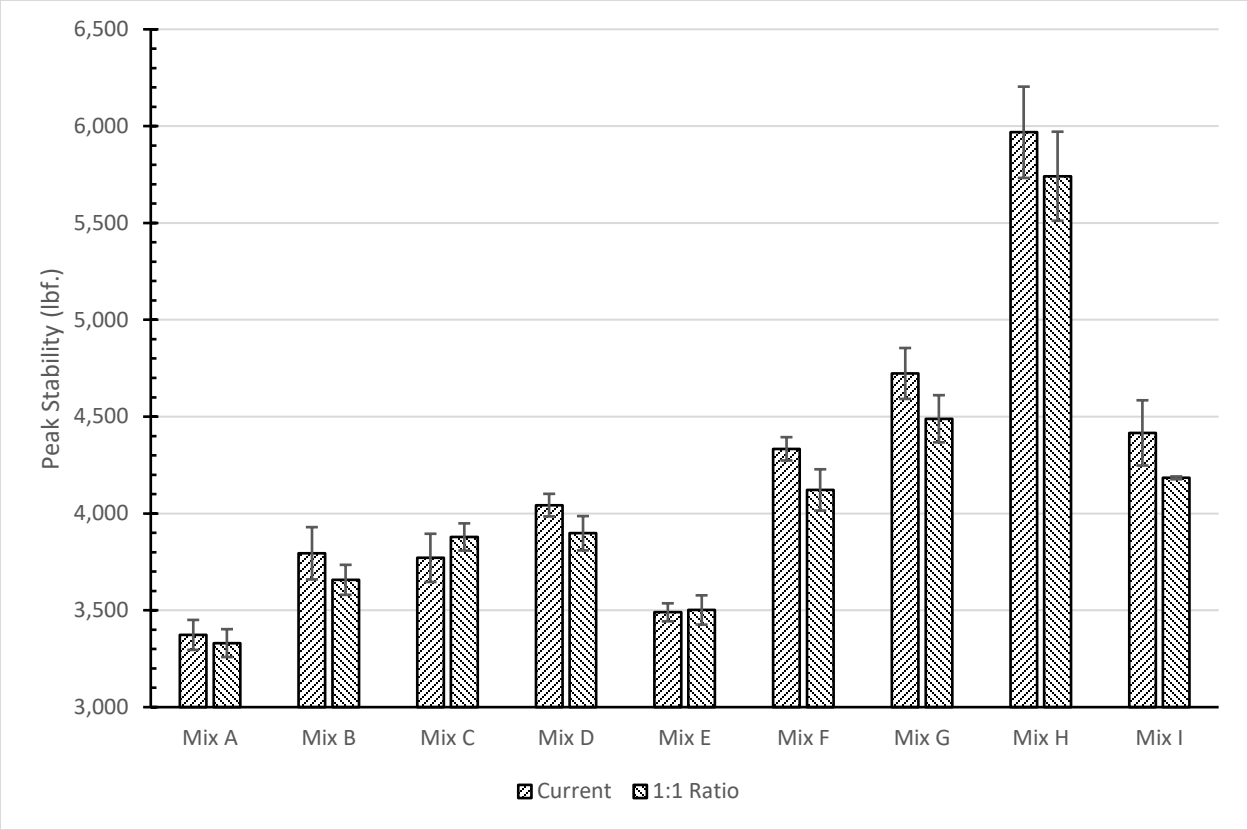

Figure 5: Peak Stability Comparison for Current vs. 1:1 Ratio Arrangement.

Consider the differences in Peak Stability between sprocket arrangements like was done for the CT Index. The second column from the right in Table 3 is the difference between the average Peak Stability values for that mix (Current – 1:1 Ratio). The right column shows the difference calculated as a percentage of the average peak stability for the Current Arrangement of that mix.

Figure 6 shows for all mixes the average Peak Stability difference between sprocket arrangements as a percentage of the current sprocket arrangement (~2.7%) and the 95% confidence interval generated using the t-test. Because the confidence interval does not cross zero, we can state with 95% confidence that the average Peak Stability is about 2.7% lower for the 1:1 Ratio Arrangement when compared to the Current Arrangement.

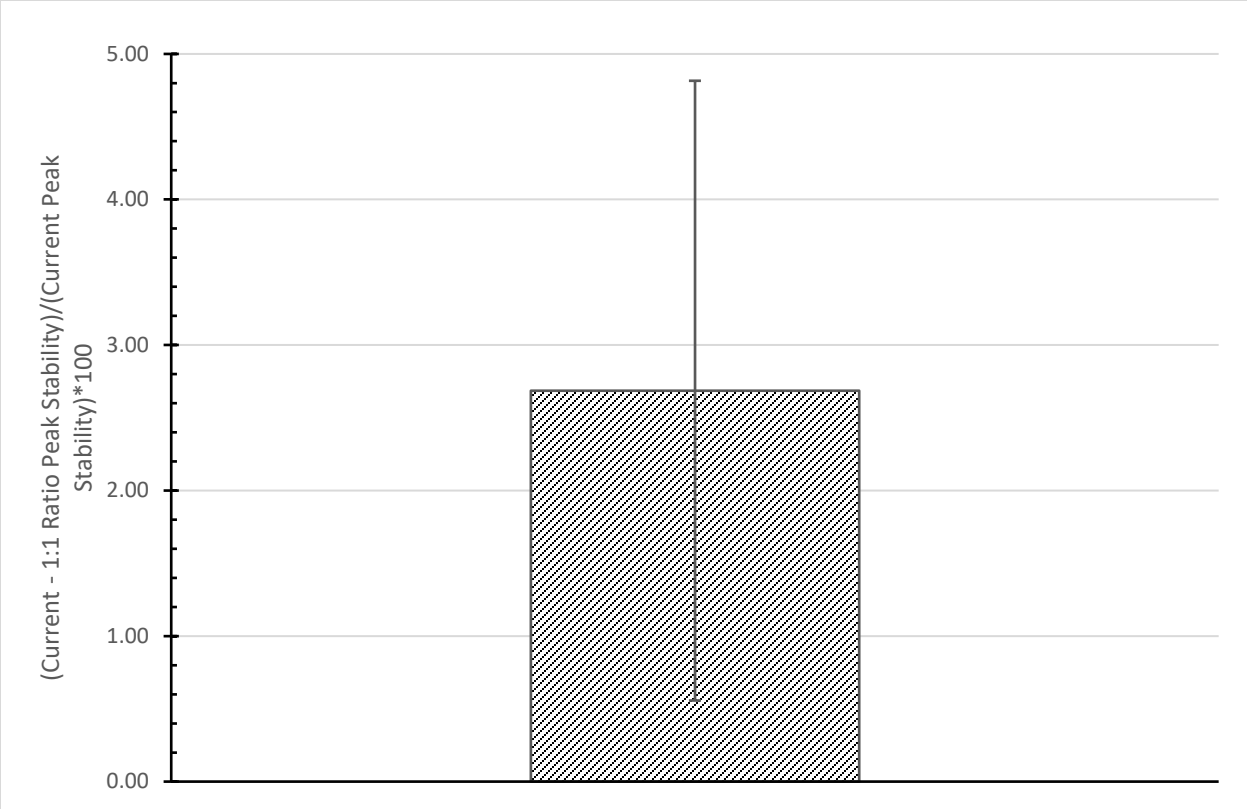

Figure 6: Difference in Peak Stability from Current to 1:1 Ratio Arrangement.

What does Pine recommend with respect to sprocket arrangement?

1. What is the specimen deformation rate required by the test you need to run? ASTM D8225-19 Section 6.1.1 specifies 50 ± 2 mm/min. Some state specification allow a tolerance greater than ± 2 mm/minute. The requirement of the test you must run will lead you to a decision.

   The data presented shows the Current Arrangement runs at an average of 54.56 mm/min with a standard deviation of ± 0.23 mm/min. The range is 53.98 to 55.49 mm/min.

   The data presented shows the 1:1 Ratio Sprocket Arrangement runs at an average of 51.11 mm/min with a standard deviation of ± 0.21 mm/min. The range is 50.66 to 51.56 mm/min.

2. Is the potential impact on peak stability acceptable?

   The individual mix data was inconclusive. Of the 9 mixes tested, only Mixes F and I showed a statistically significant difference in peak stability between sprocket arrangements. However, a t-test analysis of the differences between the average peak stability values for each sprocket arrangement by mix indicates with 95% confidence that the 1:1 Ratio generates a peak stability that is about 2.7% lower than the peak stability using the Current Arrangement.

What does Pine recommend with respect to paper vs. digital recorder?

The specimen deformation rate issue addressed by the changing the sprocket arrangement is not affected by the recorder. The performance of both recorders remains the same regardless of the sprocket arrangement. They merely record stability and flow in time.

Table 4: Specimen Deformation Rate Data.

Mix	Specimen	Specimen Deformation Rate (mm/min)			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
A	1	54.52	All Data Average = 54.45 Std. Dev. = ± 0.22 Without Outlier Average = 54.52 Std. Dev. = ± 0.12	51.10	All Data Average = 50.97 Std. Dev. = ± 0.20
	2	54.35		51.08	
	3	53.98*		50.66	
	4	54.73		51.00	
	5	54.53		51.25	
	6	54.56		50.99	
	7	54.43		51.00	
	8	54.50		50.71	
B	1	54.62	All Data Average = 54.74 Std. Dev. = ± 0.15	51.29	All Data Average = 51.27 Std. Dev. = ± 0.12
	2	54.76		51.35	
	3	54.63		51.13	
	4	54.76		51.47	
	5	54.60		51.29	
	6	54.87		51.07	
	7	55.04		51.28	
	8	54.67		51.26	
C	1	54.62	All Data Average = 54.53 Std. Dev. = ± 0.09	51.26	All Data Average = 51.07 Std. Dev. = ± 0.20
	2	54.59		50.83	
	3	54.40		51.31	
	4	54.64		51.13	
	5	54.53		51.20	
	6	54.55		50.99	
	7	54.41		50.75	
	8	54.48		51.11	
D	1	54.57	All Data Average = 54.58 Std. Dev. = ± 0.07 Without Outlier Average = 54.60 Std. Dev. = ± 0.03	51.31	All Data Average = 51.13 Std. Dev. = ± 0.12
	2	54.66		51.06	
	3	54.56		51.06	
	4	54.61		51.25	
	5	54.59		50.98	
	6	54.62		51.22	
	7	54.44*		51.14	
	8	54.61		51.04	
E	1	54.04	All Data Average = 54.32 Std. Dev. = ± 0.17	50.92	All Data Average = 50.93 Std. Dev. = ± 0.16
	2	54.26		50.77	
	3	54.44		50.93	
	4	54.44		50.87	
	5	54.25		50.75	
	6	54.16		51.23	
	7	54.46		51.06	
	8	54.50		50.90	
F	1	54.48	All Data Average = 54.67 Std. Dev. = ± 0.17	50.93	All Data Average = 51.17 Std. Dev. = ± 0.16
	2	54.94		51.31	
	3	54.64		51.22	
	4	54.75		51.16	
	5	54.62		51.28	
	6	54.44		50.93	
	7	54.72		51.21	
	8	54.80		51.31	

Table 4: Specimen Deformation Rate Data (continued).

Mix	Specimen	Specimen Deformation Rate (mm/min)			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
G	1	54.47	All Data Average = 54.43 Std. Dev. = ± 0.22	51.13	All Data Average = 51.09 Std. Dev. = ± 0.13
	2	54.32		50.95	
	3	54.85		50.87	
	4	54.59		51.25	
	5	54.18		51.13	
	6	54.54		51.04	
	7	54.77		51.23	
	8	54.51		51.08	
H	1	54.52	All Data Average = 55.05 Std. Dev. = ± 0.38	51.56	All Data Average = 51.47 Std. Dev. = ± 0.16 Without Outlier Average = 51.54 Std. Dev. = ±0.03
	2	55.49+		51.56	
	3	55.13		51.53	
	4	55.24		51.50	
	5	54.88		51.19*	
G	1	54.38	All Data Average = 54.43 Std. Dev. = ± 0.11	50.83	All Data Average = 50.88 Std. Dev. = ± 0.15
	2	54.57		50.69	
	3	54.47		51.01	
	4	54.31		50.99	

* Identified as an outlier according to ASTM E178.

+ Identified as an outlier when considering all data as a single data set according to ASTM E178.

Table 5: CT Index Results.

Mix	Specimen	CT Index			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
A	1	36.3	All Data Average = 48.7 Std. Dev. = ± 8.5	55.9	All Data Average = 52.1 Std. Dev. = ± 7.1 Without Outlier Average = 54.3 Std. Dev. = ± 3.6
	2	56.3		50.0	
	3	61.8		49.6	
	4	41.4		54.3	
	5	45.6		36.6*	
	6	50.1		56.7	
	7	54.6		54.3	
	8	43.7		59.6	
B	1	45.8	All Data Average = 40.4 Std. Dev. = ± 5.9	40.4	All Data Average = 39.3 Std. Dev. = ± 5.4 Without Outlier Average = 40.9 Std. Dev. = ± 2.9
	2	41.6		36.9	
	3	50.4		43.7	
	4	40.5		27.8*	
	5	41.7		42.1	
	6	34.8		41.5	
	7	34.7		37.5	
	8	33.3		44.5	
C	1	57.1	All Data Average = 55.7 Std. Dev. = ± 16.7 Without Outlier Average = 50.6 Std. Dev. = ± 8.7	39.6	All Data Average = 55.2 Std. Dev. = ± 11.0
	2	49.3		63.6	
	3	48.8		52.4	
	4	48.0		38.4	
	5	38.3		55.4	
	6	46.7		63.8	
	7	91.9*		62.0	
	8	65.8		66.0	
D	1	58.2	All Data Average = 55.5 Std. Dev. = ± 7.3	44.6	All Data Average = 56.8 Std. Dev. = ± 6.9
	2	48.8		65.0	
	3	43.4		54.5	
	4	58.5		51.4	
	5	67.4		65.0	
	6	59.8		58.0	
	7	54.1		60.5	
	8	53.5		55.0	
E	1	84.7	All Data Average = 70.3 Std. Dev. = ± 13.8	63.8	All Data Average = 68.1 Std. Dev. = ± 14.8 Without Outlier Average = 63.6 Std. Dev. = ± 8.5
	2	82.9		59.1	
	3	76.4		72.9	
	4	60.6		68.1	
	5	79.9		99.0*	
	6	75.5		49.6	
	7	52.7		58.8	
	8	50.0		73.1	
F	1	75.2	All Data Average = 59.0 Std. Dev. = ± 8.6	78.3	All Data Average = 68.8 Std. Dev. = ± 8.7
	2	47.2		67.5	
	3	61.4		81.6	
	4	57.9		68.6	
	5	59.2		56.2	
	6	62.8		73.6	
	7	59.1		64.0	
	8	49.4		60.6	

* Identified as an outlier according to ASTM E178.

Table 5: CT Index Results (continued).

Mix	Specimen	CT Index			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
H	1	65.3	All Data Average = 53.0 Std. Dev. = ± 19.9	64.1	All Data Average = 61.3 Std. Dev. = ± 14.5
	2	33.0		53.5	
	3	37.2		45.7	
	4	49.0		58.1	
	5	80.6		85.0	
I	1	131.5	All Data Average = 103.1 Std. Dev. = ± 22.2	122.1	All Data Average = 113.8 Std. Dev. = ± 24.8
	2	77.3		144.5	
	3	102.2		99.7	
	4	101.2		88.7	

* Identified as an outlier according to ASTM E178.

Table 6: Peak Stability Data.

Mix	Specimen	Peak Stability (kN)			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
A	1	15.1	All Data Average = 15.2 Std. Dev. = ± 0.6 Without Outliers Average = 15.0 Std. Dev. = ± 0.3	14.5	All Data Average = 14.8 Std. Dev. = ± 0.3
	2	15.1		14.6	
	3	14.6		15.2	
	4	16.5*		15.0	
	5	14.9		15.3	
	6	15.6		14.7	
	7	14.6		14.5	
	8	15.2		14.6	
B	1	16.5	All Data Average = 16.9 Std. Dev. = ± 0.6	16.2	All Data Average = 16.3 Std. Dev. = ± 0.4
	2	16.8		15.8	
	3	16.8		15.8	
	4	17.6		16.8	
	5	16.3		16.3	
	6	16.8		16.2	
	7	18.0		16.5	
	8	16.3		16.5	
C	1	17.1	All Data Average = 16.8 Std. Dev. = ± 0.6	17.5	All Data Average = 17.4 Std. Dev. = ± 0.5 Without Outliers Average = 17.3 Std. Dev. = ± 0.3
	2	16.1		18.5*	
	3	17.6		17.2	
	4	16.5		16.9	
	5	16.1		17.4	
	6	17.4		17.2	
	7	16.6		16.9	
	8	16.9		17.7	
D	1	17.7	All Data Average = 18.0 Std. Dev. = ± 0.3	16.8	All Data Average = 17.3 Std. Dev. = ± 0.4
	2	17.9		17.0	
	3	18.2		17.5	
	4	18.2		17.9	
	5	17.7		17.5	
	6	17.7		17.4	
	7	18.2		16.9	
	8	18.4		17.7	
E	1	15.3	All Data Average = 15.6 Std. Dev. = ± 0.3	15.3	All Data Average = 15.8 Std. Dev. = ± 0.8 Without Outliers Average = 15.6 Std. Dev. = ± 0.3
	2	15.7		15.6	
	3	15.6		15.1	
	4	16.3		15.7	
	5	15.5		15.3	
	6	15.2		17.6*	
	7	15.5		16.0	
	8	15.8		15.9	
F	1	18.1*	All Data Average = 19.1 Std. Dev. = ± 0.5 Without Outliers Average = 19.3 Std. Dev. = ± 0.3	18.0	All Data Average = 18.3 Std. Dev. = ± 0.5
	2	19.3		18.8	
	3	19.4		19.1	
	4	19.6		17.7	
	5	19.2		18.0	
	6	18.8		18.2	
	7	19.1		18.6	
	8	19.5		18.4	
G	1	21.4	All Data Average = 21.0 Std. Dev. = ± 0.6	19.5	All Data Average = 20.0 Std. Dev. = ± 0.5
	2	21.4		19.4	
	3	21.9		19.5	
	4	21.0		20.2	
	5	20.2		20.3	
	6	20.6		20.5	
	7	21.0		20.7	
	8	20.4		19.6	

* Identified as an outlier according to ASTM E178.

Table 6: Peak Stability Data (continued).

Mix	Specimen	Peak Stability (kN)			
		Current Sprocket Arrangement		1:1 Ratio Sprocket Arrangement	
H	1	25.6	All Data Average = 26.6 Std. Dev. = ± 1.0	26.4	All Data Average = 25.5 Std. Dev. = ± 1.0
	2	27.3		24.5	
	3	27.3		26.7	
	4	27.2		25.5	
	5	25.2		24.6	
I	1	19.9	All Data Average = 19.6 Std. Dev. = ± 0.7	18.6	All Data Average = 18.6 Std. Dev. = ± 0.0
	2	18.6		18.2*	
	3	19.8		18.6	
	4	20.3		18.6	

* Identified as an outlier according to ASTM E178.