Chapter 4 – Results and Discussion

This chapter is an examination of the data received from six-hundred thirty single-shear connection tests, one-hundred eighty bearing resistance tests, and ninety-six density profile analyses. The data were collected, statistically evaluated, and presented graphically for discussion. In addition, comparisons were made between observed yield values and those calculated with the general dowel equations. In general, the test results are summarized and discussed according to the physical or mechanical changes observed in response to cyclic humidity exposure.

Each testing machine's associated data acquisition system produced an output computer file after each laboratory test. The data within the files were then analyzed in a variety of ways. A computer program interpreted the load/displacement data from the connection and bearing resistance tests. In terms of the density profile investigations, the data acquisition program (linked to the densitometer) produced an output file, which was examined with another custom computer program. This 'macro' was capable of performing computations and formatting values for visual presentation.

The test results displayed in this chapter are ordered by connection type (i.e., 'Mill A', 'Mill B', etc.). Specifically, the results related to each individual connection type are presented in context to the following topics:

- Moisture contents and specific gravities of test specimens
- Connection elastic stiffness performance
- 5% offset yield performance
- Maximum yield performance
- Failure observations
- Density profile observations
- Yield estimation using the general dowel equations

Analysis of variation (ANOVA) procedures, two-tailed t-tests, and Fisher's least squares difference (LSD) tests were performed for comparisons of performance parameters among treatments (0, 1, 5, 10, 15, 25, and 40 cycles) within each block (Mill

A, B, C, D, E, and F). All statistical tests were performed using an alpha value of 0.05 to concur with a 95% confidence interval (CI). Complete results from each test are provided in the appendices.

As a note, the average deviations above and below the mean values are represented by the vertical error bars in the plots of connection performance versus cycling times. In addition, with the inclusion of a 95% CI it is necessary that any ANOVA p-value be less than 0.05 to denote an overall significant difference among a group of sample means. Furthermore, a t-test requires the calculated t-statistics to be greater than the t-critical values to confirm a significant difference between individual means.

4.1 – 'Mill A' Connections

'Mill A' connections were made from a stud grade SF main member and 7/16 in. OSB side member. A 6d uncoated wire nail was used as the fastener. Table 4.1 provides summary statistics for observed performance parameters during all cycle periods. This connection configuration afforded a maximum yield near 275 lbs. at about 1.0 in. of slip. Figure 4.1 depicts the load/slip plot of sample A3-9, a curve similar to nearly all 'Mill A' connections.

Table 4.1: Observed metrics and predictions of 'Mill A' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (A1)	mean	6354	109	267	78.6%	21.4%
	COV	46.0%	16.4%	19.2%		
1 cycle (A2)	mean	5763	102	198	93.3%	6.7%
	COV	66.3%	23.8%	19.0%		
5 cycles (A3)	mean	6490	95	220	86.7%	13.3%
	COV	44.9%	16.8%	27.6%		
10 cycles (A4)	mean	6100	102	220	86.7%	13.3%
	COV	36.1%	13.4%	22.1%		
15 cycles (A5)	mean	3795	106	272	73.3%	26.7%
	COV	34.6%	17.1%	20.5%		
25 cycles (A6)	mean	3786	111	287	60.0%	40.0%
	COV	26.7%	11.1%	21.0%		
40 cycles (A7)	mean	4742	82	257	57.1%	42.9%
	COV	33.8%	11.0%	16.9%		
Yield Model Prediction	**Lateral Resistance (lb)**		**105**			
	Yield Mode		III_s			

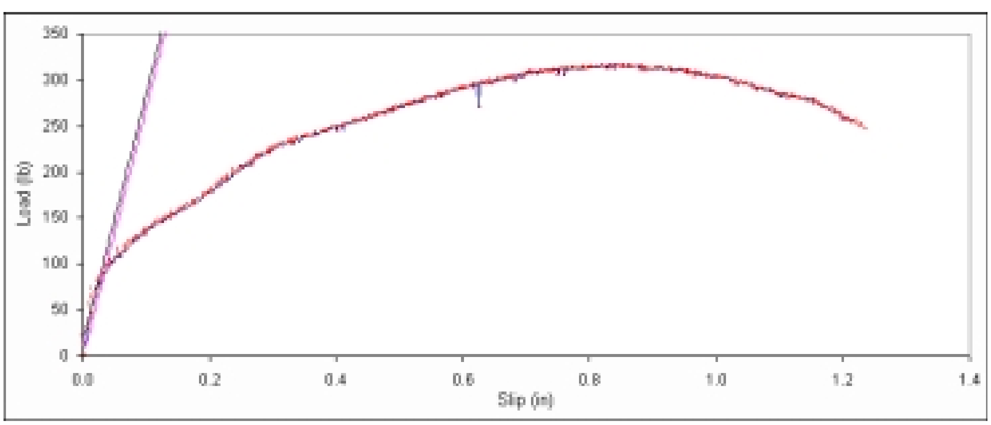


Figure 4.1: Typical load/slip plot of a 'Mill A' connection (sample A3-9).

4.1.1 – Moisture Contents and Specific Gravities

As stated in the previous chapter, samples were cut from each tested connection for moisture content (MC) and specific gravity (SG) determination in an effort to ensure uniformity. SG measurements were based on oven dry weight and volume. Note that all connection tests, MC, and SG measurements were performed after the samples had completed the dry cycle. In this case, the main member components were found to have MC values between 10.5% and 11.3%. Minimal variation was observed in the datasets as indicated by an overall coefficient of variation (COV) value of 2.4%. Side member samples were more variable with a COV of 8.4% and MC values ranging between 8.0% and 10.2%. All materials involved in the initial tests of the control connections (0 cycles) were not subjected to the cyclic humidity conditions, but instead were allowed to equilibrate to 12% MC within a conditioning chamber prior to testing. SG values of main members were representative of the spruce and fir species involved with a mean value of 0.35 and 4.0% COV. Side member specific gravities were higher and less variable with a mean value of 0.69 and a 3.1% COV. Individual MC and SG values for each treatment group are given in Table 4.2, below.

Table 4.2: Moisture content (at testing) and specific gravity values of 'Mill A' connection components.

		Main Member				Side Member			
		% moisture content		specific gravity		% moisture content		specific gravity	
		mean	COV	mean	COV	mean	COV	mean	COV
conditioning cycles	0	12 *	---	0.36	8.3%	12 *	---	0.67	6.1%
	1	10.6	1.0%	0.35	8.4%	8.0	5.5%	0.68	6.0%
	5	10.8	7.7%	0.33	9.3%	9.5	3.2%	0.69	5.7%
	10	11.2	4.2%	0.36	6.7%	9.7	2.6%	0.69	6.1%
	15	11.2	11.6%	0.33	4.5%	10.2	6.3%	0.73	6.4%
	25	11.2	5.6%	0.37	7.5%	10.0	2.0%	0.67	4.4%
	40	11.1	3.9%	0.36	6.2%	9.5	4.2%	0.68	5.1%
Overall		**11.0**	**2.4%**	**0.35**	**4.0%**	**9.5**	**8.4%**	**0.69**	**3.1%**

** Zero cycle connections (controls) assumed 12% MC.*

4.1.2 – Elastic Stiffness Performance

Elastic stiffness values of 'Mill A' connections appear to be equivalent between the control and 10th cycle observations, as shown in Figure 4.2. The mean values then decrease in the 15th and 25th cycles, but increase slightly in the last cycle. A p-value of 0.0034 indicates there are significant differences among mean values within a 95% CI. A two-tailed t-test, seen in Table 4.3, specifies that significant differences exist between the control and 15th cycle connection tests. Furthermore, Fisher's LSD procedure provides order sequencing and grouping which infers that the elastic stiffness values are decreasing as cycling continues (Table 4.4). Two groupings are shown with the control, 1st, 5th, and 10th cycle results in a group and 15th, 25th, and 40th cycle results in another. This indicates an overall decrease in elastic stiffness as conditioning continues. Realistic assumptions are possible past the 40th cycle as the last series of observations were significantly the same. It is likely that the elastic stiffness values will remain similar or continue to decline.

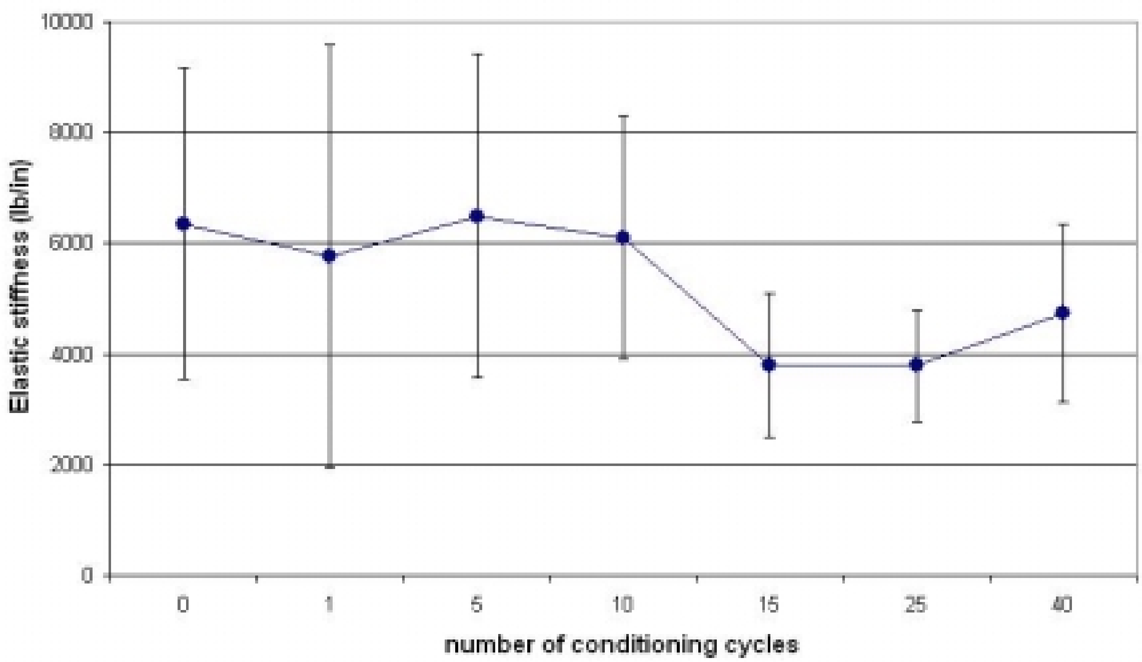


Figure 4.2: Observed elastic stiffness values of 'Mill A' connections.

Table 4.3: Two tailed t-test results of 'Mill A' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.482	2.056	NO
1	5	0.676	2.064	NO
0	5	0.314	2.056	NO
0	10	0.155	2.060	NO
0	15	3.188	2.086	YES
15	25	0.019	2.056	NO
15	40	1.809	2.052	NO

Table 4.4: Fisher's LSD results of 'Mill A' elastic stiffness values (95% CI).

Treatment (cycles)	5	0	10	1	40	15	25
mean:	6490	6354	6100	5763	4742	3795	3787
grouping:	A	A	A	A	A		
					B	B	B

4.1.3 – 5% Offset Yield Performance

As illustrated in Figure 4.3, the performance of 'Mill A' connections, with respect to the 5% offset yield loads, is relatively unchanging until after the 25th cycle, when the results fall by 27% to the 40th cycle. A p-value of <0.001 supports the rejection of the null hypothesis and indicates significant differences among mean values is present. Based on a 95% CI, a t-test reveals differences in mean values between the control (0 cycles) and 5th cycle test results. Furthermore, major contrasts are recognized between 5th and 25th cycles and between the 25th and 40th cycle observations (Table 4.5). Sustaining the claims of the two-tailed t-test, Fisher's LSD test concludes that three groupings exist among the data with the 40th cycle results in its own group (Table 4.6).

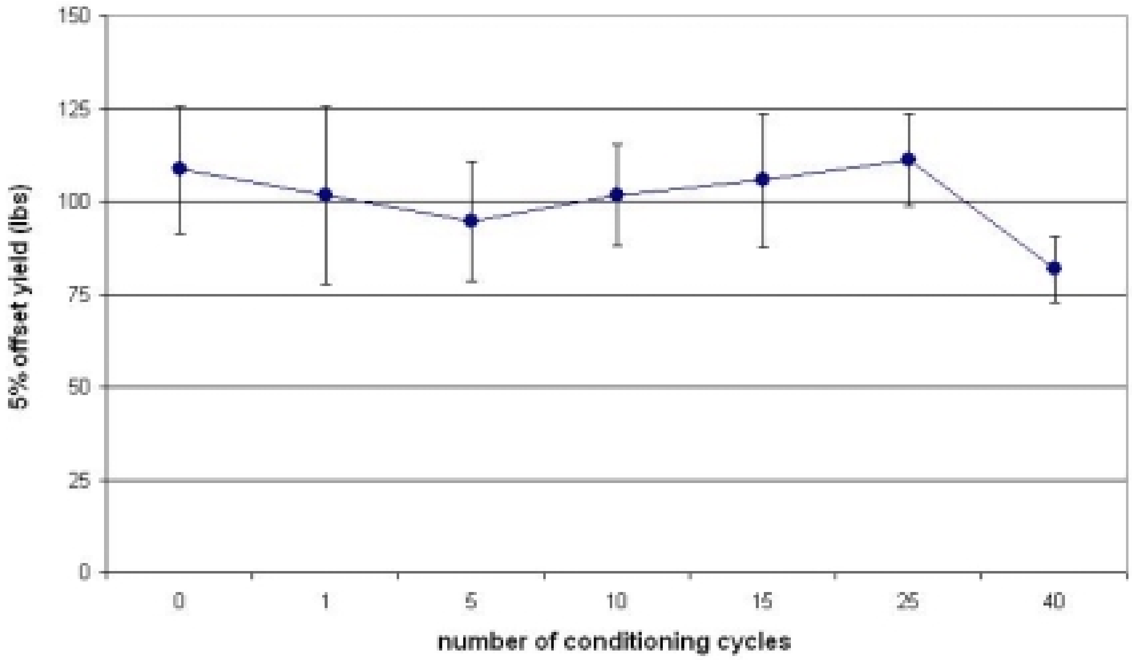


Figure 4.3: Observed 5% offset loads of 'Mill A' connections.

Table 4.5: Two tailed t-test results of 'Mill A' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.917	2.060	NO
1	5	0.940	2.064	NO
0	5	2.323	2.048	YES
5	10	1.293	2.052	NO
5	15	1.766	2.048	NO
5	25	3.161	2.056	YES
15	25	0.971	2.060	NO
25	40	7.549	2.060	YES

Table 4.6: Fisher's LSD results of 'Mill A' 5% offset yield values (95% CI).

Treatment (cycles)	25	0	15	10	1	5	40
mean:	111	109	106	102	102	95	82
grouping:	A	A	A	A	A		
			B	B	B	B	
							C

4.1.4 – Maximum Yield Performance

The maximum yield performance of 'Mill A' connections ranged between approximately 200 to 290 lbs., in terms of average test values (Figure 4.4). A p-value of <0.0001 is produced by an ANOVA procedure. More specifically, a t-test points out significant differences between the 0 (control) and 1st cycles, 1st and 15th, and the 10th and 15th test results (Table 4.7). Groupings are given in Table 4.8, which indicates three overlapping sets with the first cycles appearing at the lower end of the spectrum and the middle range test values near the top. While an initial decrease of the maximum load performance was found after the 0 cycle tests, the values slowly rebounded to a level equal to the control test in the 25th cycle, only to decrease again at the 40th cycle.

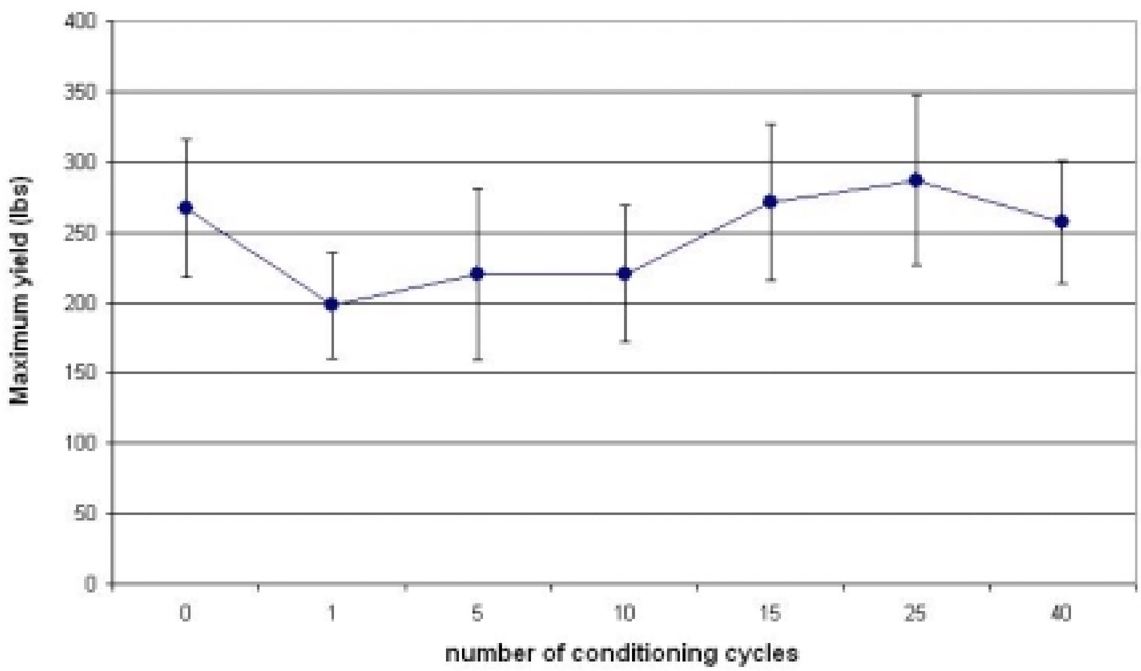


Figure 4.4: Observed maximum loads of 'Mill A' connections.

Table 4.7: Two tailed t-test results of 'Mill A' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	4.302	2.056	YES
1	5	1.203	2.069	NO
1	10	1.392	2.056	NO
1	15	4.229	2.060	YES
10	15	2.692	2.052	YES
15	25	0.725	2.048	NO
15	40	0.793	2.056	NO

Table 4.8: Fisher's LSD results of 'Mill A' maximum yield values (95% CI).

Treatment (cycles)	**25**	**15**	**0**	**40**	**5**	**10**	**1**
mean:	287	272	267	257	220	220	198
grouping:	A	A	A	A			
				B	B		
					C	C	C

The probability distribution of the maximum loads observed from 'Mill A' connections at each cycling interval is presented in Figure 4.5, below. The curves were obtained using a Weibull probability density function (PDF), which utilizes scale and shape factors to describe the distribution shapes. These values are provided in Table 4.9. A shift in distribution spread is observed between the control and 1st cycle results and the longer cycled connections. This is expressed by differences between the tall and short height of the curves. The distributions of the 25th and 40th cycle observations are spread out between a greater range of maximum load values and show an overall increase in load capacity as cycling time is increased.

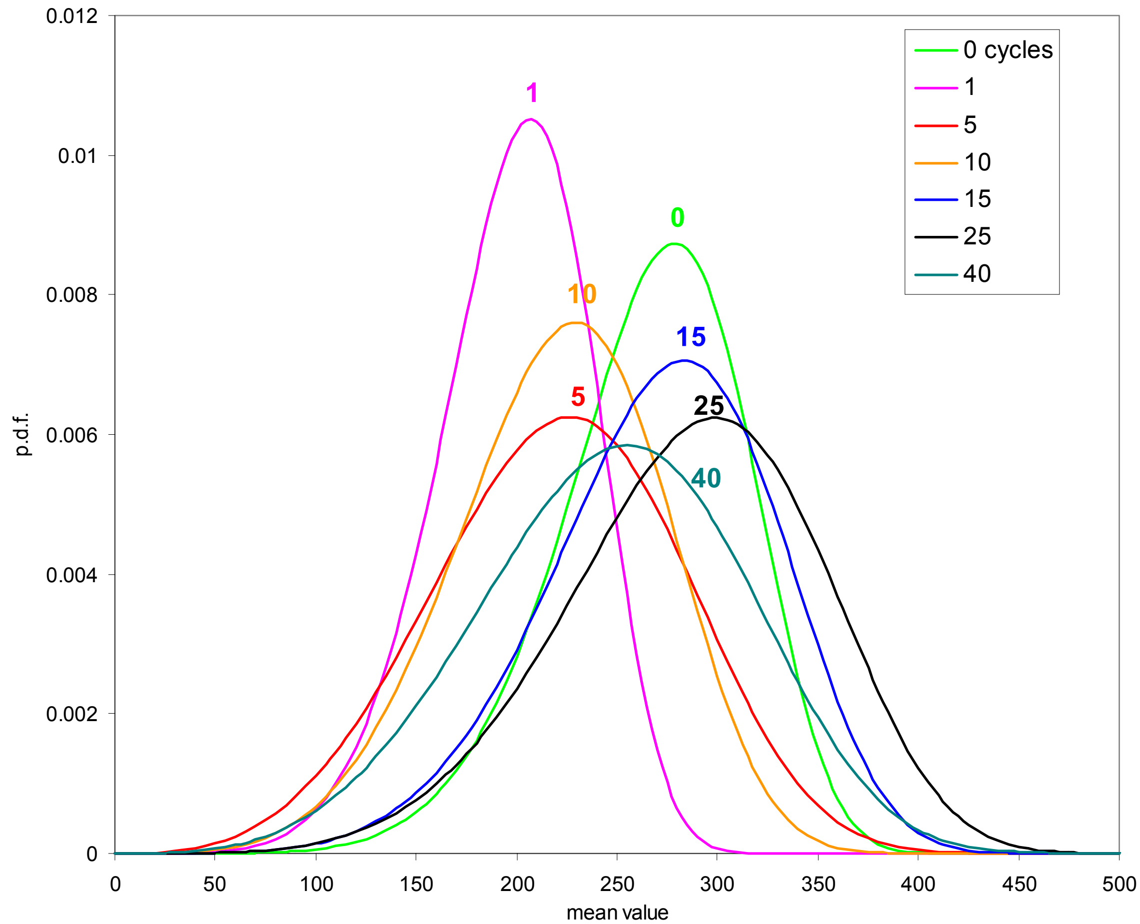


Figure 4.5: Probability density distributions of maximum yield loads for 'Mill A' connections (0-40 cycles).

Table 4.9: Weibull distribution parameters.

cycle:	**0**	**1**	**5**	**10**	**15**	**25**	**40**
scale, *a*	285.43	213.35	243.41	240.46	293.77	311.54	272.13
shape, *b*	6.70	6.01	4.00	4.85	5.54	5.18	4.20

4.1.5 – Failure Yield

The yield modes exhibited at failure for the 'Mill A' connections were limited to Modes III_m and III_s. Crushing within the main member caused the majority of failure yields, but as cycling times increased the occurrence of crushing within the side member became more common. Table 4.10 presents the percentage of failures caused by either Mode III_m or III_s after each specified cycling interval.

Table 4.10: Yield modes observed at failure for 'Mill A' connections.

		0	1	5	10	15	25	40
Mode	**III_m**	78.6%	93.3%	86.7%	86.7%	73.3%	60.0%	57.1%
	III_s	21.4%	6.7%	13.3%	13.3%	26.7%	40.0%	42.9%

The connections, which failed because of main member crushing, did not exhibit any apparent damage to the side member. Figure 4.6 is a photograph of such a connection after testing.

Figure 4.6: Mode III_m failure of sample A6-11 (25 cycles).

There were instances when the nail shanks rotated laterally during testing causing the top region of the nail head to be partially embedded in the side member material, in this case a 7/16 in. OSB product. This type of event usually resulted in Mode III_m failure yields unless the bearing resistance of the main member material was adequately higher, which would then initiate a Mode III_s failure yield. An example of a connection that exhibited this behavior is shown in Figure 4.7. Notice the top portion of the nail head is pulled into the side member face. If the main member material had not failed first, this weakening of the side member would have caused the failure.

Figure 4.7: Mode III_m failure of sample A3-15 (5 cycles).

As previously stated, Mode III_s failure yields become more frequent as cycling progressed. This was a result of presumed deterioration within the side member materials. The outcome of the weakened OSB caused Mode III_s failure yields as seen in Figure 4.8. In this case, the nail head was actually pulled completely into the side member material and is not clearly visible in the photograph. Again, the area of interest, the nail hole, is within the circle.

Figure 4.8: Mode III_s failure of sample A3-1 (5 cycles).

4.1.6 – Density Analysis

Vertical density profile (VDP) samples representing main and side member materials were exposed to identical cycling regimes as conditioning times were the same for both the connections and their VDP counterparts. Figure 4.9 shows the mean density values of 'Mill A' type sheathing after 0 (control), 1, 5, 10, 15, 20, 25, and 30 cycles. Because of time constraints, VDP sample cycling only continued to 30 cycles and were analyzed at five cycle intervals after the initial two measurements. To reiterate, this is unlike the testing regime for the connection samples, which were evaluated after 0 (control), 1, 5, 10, 15, 25, and 40 cycles. Furthermore, it should be stated that the connection samples were only tested once because loading caused structural failure, but VDP analysis is a non-destructive technique and specimens can be tested repeatedly. The plot below clearly shows a decreasing trend in average density as cycling progresses.

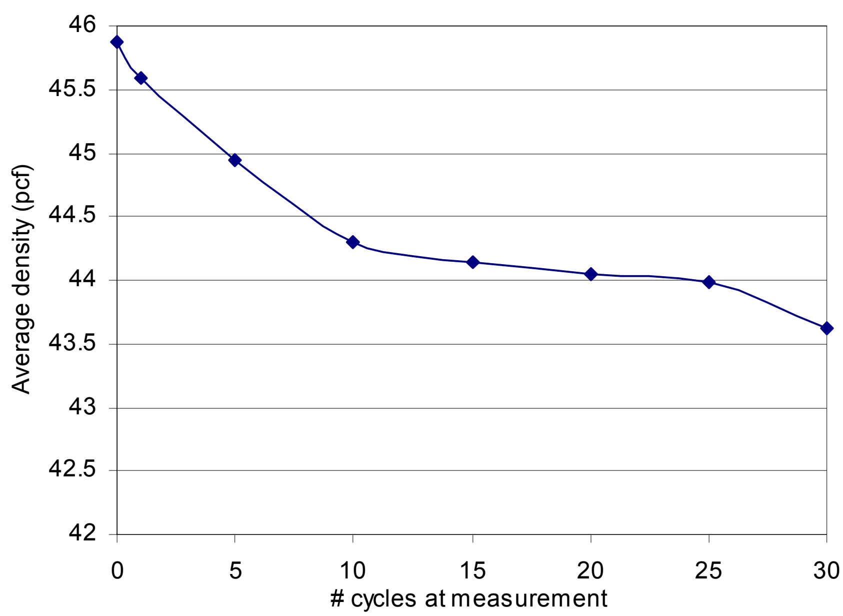


Figure 4.9: Average density of 'Mill A' sheathing after treatments.

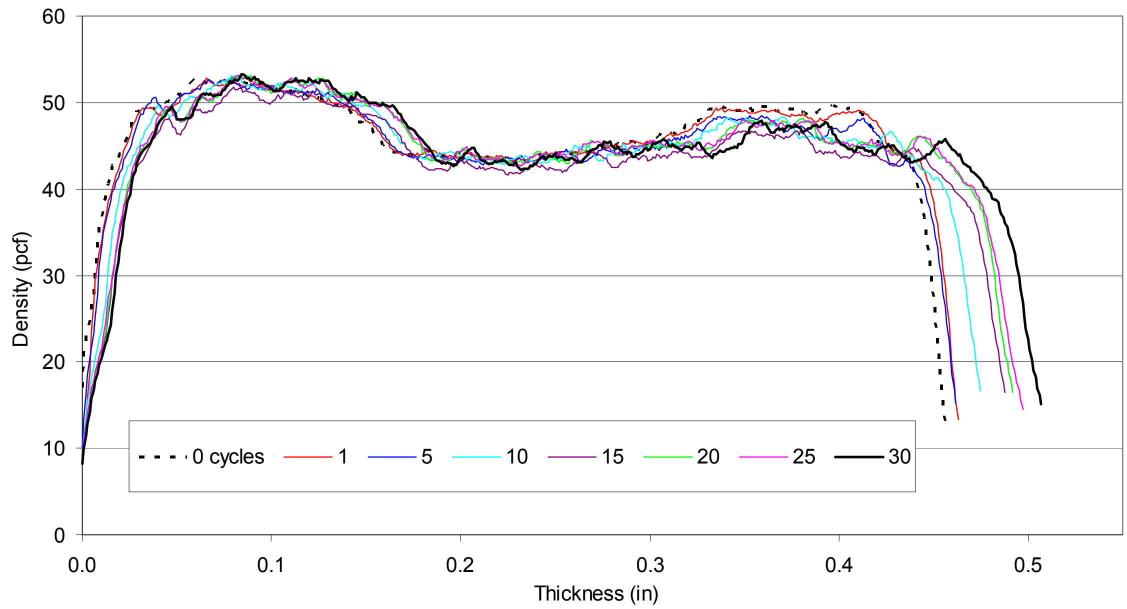


Figure 4.10: Overlay of 'Mill A' vertical-density profiles.

Table 4.11: Relative and cumulative changes in thickness of 'Mill A' sheathing.

		# cycles at measurement						
		1	5	10	15	20	25	30
Mill A	Vs. previous	1.4%	0.3%	3.6%	3.1%	0.7%	0.6%	2.4%
	Vs. control	1.4%	1.7%	5.4%	8.7%	9.5%	10.1%	12.7%

Above, Figure 4.10 provides complete density information across the entire thickness of 'Mill A' type sheathing throughout cyclic humidity exposure. Again, this is an average of two samples, randomly selected and cut from 'Mill A' type panels, and conditioned alongside the connection specimens. Changes between vertical density gradients are observed in a stepwise downward direction as cycling increases. Also evident, is the thickness increase indicated in the plot as cycling increases. This is described as *unrecoverable thickness swell* and is attributed to overall de-densification and therefore, deterioration of the samples caused by repeated absorption and desorption of moisture from the environment. Each measurement was taken systematically after each dry period was completed when the lowest MC was reached. Section 4.1.1 expands on the consistency observed in MC of side member materials. The maximum observed COV value is 6.3%. Table 4.11 shows how thickness increased after each specified cycle. The unrecoverable thickness swell increases 0.3% to 3.6% between cycles and reaches a maximum at the 30th cycle with a cumulative 12.7% increase in comparison to the original control reading.

4.1.7 – Yield Model Estimation

The yield estimation of single-shear connections is based on the general dowel equations as described in Chapter 2. The input parameters involve experimental observations of the bearing resistances of both wood members and the metal fastener at the 5% offset. Figure 4.11 depicts the typical post-test condition of main and side members. Table 4.12 summarizes the data for each factor required in the yield model calculations. Note that the dowel length used in the calculations is less than the actual fastener measurement to exclude the diamond pointed tip (1.8 in. instead of 2.0 in.) as specified in the AF&PA's *General dowel equations for calculating lateral connection values – Technical Report 12* (AF&PA 1999).

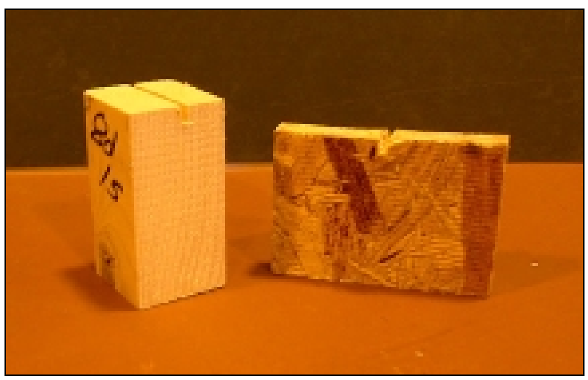


Figure 4.11: Main and side member embedment samples (post-test).

Table 4.12: Yield model input parameters for 'Mill A' connection components.

Main Member			Side Member			Fastener		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.32	2405	12.0%	0.48	5220	17.9%	0.113	41.3	4.1%

The 5% offset loads observed in 'Mill A' connection tests were compared to the 5% offset yield calculated using the general dowel equations. Estimated values were developed using non-cycled materials (only conditioned to 12% MC) and therefore, are most analogous to the 0 cycle (control) connections. As shown in Table 4.13, comparisons were made with the results from each treatment group. This was done in order to examine the validity of the yield model in cycled, or aged, connections. A Mode III_s yield was specified by the equations with a load of 105 lbs. at the 5% offset. The mode is different from what was reported at failure (Mode III_m) as the general dowel equations only estimate the mode at yield. The predicted vs. observed ratios (P/O) indicate similarities with the control group, but as experimental 5% offset values decline with increased cycling, the variation is more evident.

Table 4.13: Comparisons of observed vs. predicted 5% offset loads for 'Mill A' connections.

		Observed mean (lb)	**Observed** COV	**Predicted** (lb)	**Predicted** yield	**P/O**
conditioning cycles	0 (control)	109	16.4%	105	Mode III_s	96%
	1	102	23.8%			103%
	5	95	16.8%			111%
	10	102	13.4%			103%
	15	106	17.1%			99%
	25	111	11.1%			95%
	40	82	11.0%			128%

4.2 – 'Mill B' Connections

'Mill B' connections were prepared from stud grade SF main members and 7/16 in. OSB side members. A 6d uncoated wire nail was used as the fastener. Table 4.14 provides summary statistics for observed performance parameters throughout the cycling stages for this connection type. This joint configuration provided a maximum yield of 265 lbs. at 0.6 to 0.8 in. of slip as seen in Figure 4.12, which depicts a load/slip plot comparable to most 'Mill B' connection test results.

Table 4.14: Observed metrics and predictions of 'Mill B' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (B1)	mean	4492	100	244	60.0%	40.0%
	COV	55.5%	14.0%	21.2%		
1 cycle (B2)	mean	4516	92	187	86.7%	13.3%
	COV	55.1%	12.7%	17.0%		
5 cycles (B3)	mean	4113	90	195	93.3%	6.7%
	COV	33.8%	7.3%	25.5%		
10 cycles (B4)	mean	4577	100	214	80.0%	20.0%
	COV	37.1%	11.7%	24.6%		
15 cycles (B5)	mean	3440	91	215	73.3%	26.7%
	COV	40.3%	14.4%	24.5%		
25 cycles (B6)	mean	3620	94	260	73.3%	26.7%
	COV	23.9%	15.5%	22.3%		
40 cycles (B7)	mean	5963	87	265	66.7%	33.3%
	COV	51.5%	16.6%	21.5%		
Yield Model Prediction	**Lateral Resistance (lb)**		**94**			
	Yield Mode		III_s			

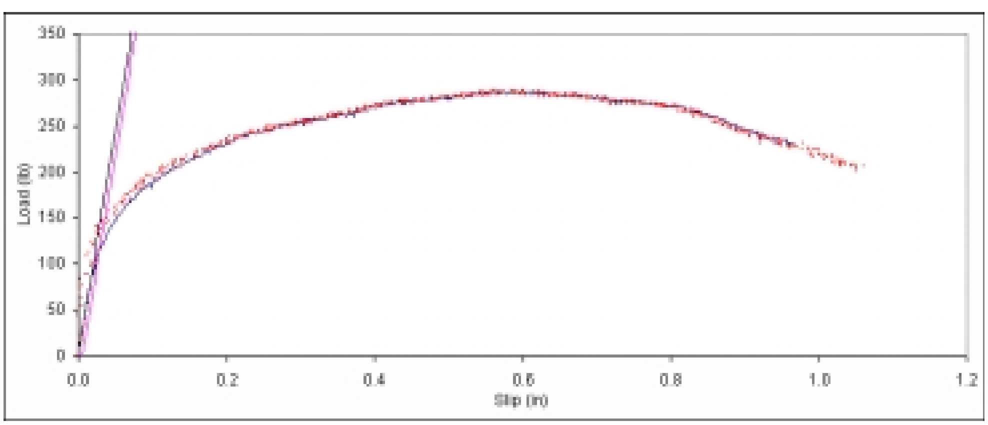


Figure 4.12: Typical load/slip plot of a 'Mill B' connection (sample B4-15).

4.2.1 – Moisture Contents and Specific Gravities

At time of testing, the connection specimens were determined to have similar attributes among the individual components as described in Table 4.15. The main members exhibited 11.08% mean MC values while the side members were slightly drier at 9.74% MC with 3.9% and 8.9% COV values, respectively. SG values were 0.36 for the main members and 0.59 for the side members with 5.9% and 3.3% COV, respectively.

Table 4.15: Moisture content (at testing) and specific gravity values of 'Mill B' connection components.

	Main Member				Side Member			
	% moisture content		specific gravity		% moisture content		specific gravity	
conditioning cycles	mean	COV	mean	COV	mean	COV	mean	COV
0	12 *	---	0.37	6.0%	12 *	---	0.58	5.6%
1	10.6	9.3%	0.37	6.0%	8.2	2.1%	0.55	5.4%
5	10.8	3.8%	0.37	5.2%	9.5	2.8%	0.60	6.4%
10	11.1	5.1%	0.33	6.2%	10.5	5.1%	0.61	5.2%
15	11.9	4.5%	0.33	6.2%	10.5	4.8%	0.61	6.5%
25	11.0	6.7%	0.36	3.6%	9.6	3.5%	0.58	6.5%
40	11.1	6.1%	0.38	4.2%	10.1	4.9%	0.60	5.7%
Overall	**11.1**	**3.9%**	**0.36**	**5.9%**	**9.7**	**8.9%**	**0.59**	**3.3%**

** Zero cycle connections (controls) assumed 12% MC.*

4.2.2 – Elastic Stiffness Performance

The mean elastic stiffness values of 'Mill B' connections seem to be nearly identical to results presented for the control group (0 cycles) through the 10th cycle values. The 15th and 25th cycle results are similar and then a dramatic increase is evident in the 40th cycle observations, as seen in Figure 4.13. Statistically speaking, an ANOVA test produces a p-value of 0.0299 at a 95% CI ($\alpha = 0.05$), which indicates significant differences among the mean elastic stiffness values. However, a two-tailed t-test, also using $\alpha = 0.05$, does not find any significant differences among the mean values (Table 4.16). This finding is most likely the result of the high level of variability observed in the test values. A LSD procedure resolves a grouping scenario that depicts two overlapping sets, but the order leads to limited inference as the control and 40th cycle results are in the same group (Table 4.17).

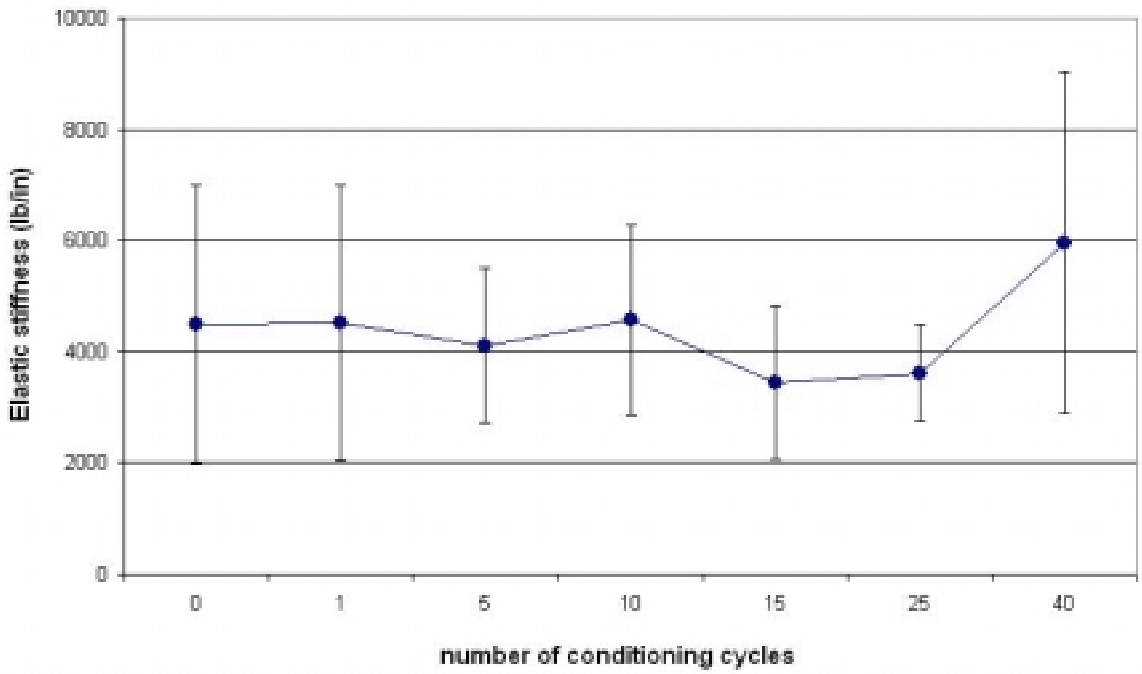


Figure 4.13: Observed elastic stiffness values of 'Mill B' connections.

Table 4.16: Two tailed t-test results of 'Mill B' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.026	2.048	NO
1	5	0.548	2.074	NO
0	5	0.514	2.074	NO
0	10	0.108	2.060	NO
0	15	1.427	2.074	NO
0	25	1.279	2.110	NO
0	40	1.440	2.052	NO
25	40	2.0041	2.0639	NO

Table 4.17: Fisher's LSD results of 'Mill B' elastic stiffness values (95% CI).

Treatment (cycles)	40	10	1	0	10	25	15
mean:	5963	4577	4516	4492	4113	3620	3440
grouping:	A	A B	A B	A B	B	B	B

4.2.3 – 5% Offset Yield Performance

The 5% offset yield observations of 'Mill B' connection presented no definite trend as cycling time increased. In Figure 4.14, an initial decrease in test results is indicated, but then an increase was seen at the 5th cycle followed by another down-sloping trend through the last tests performed at the 40th cycle point. A p-value of 0.0373 reveals significant differences and appropriately, the t-test states the variations are between the control and 5th cycles, 5th and 10th, and the 10th and 40th cycle results (Table 4.18). Furthermore, the LSD results support these claims by organizing the uppermost and lowermost mean values in their own separate groups, however the least significant difference between the two groups is not enough to completely detach the groups from each other and so, they are overlapping (Table 4.19).

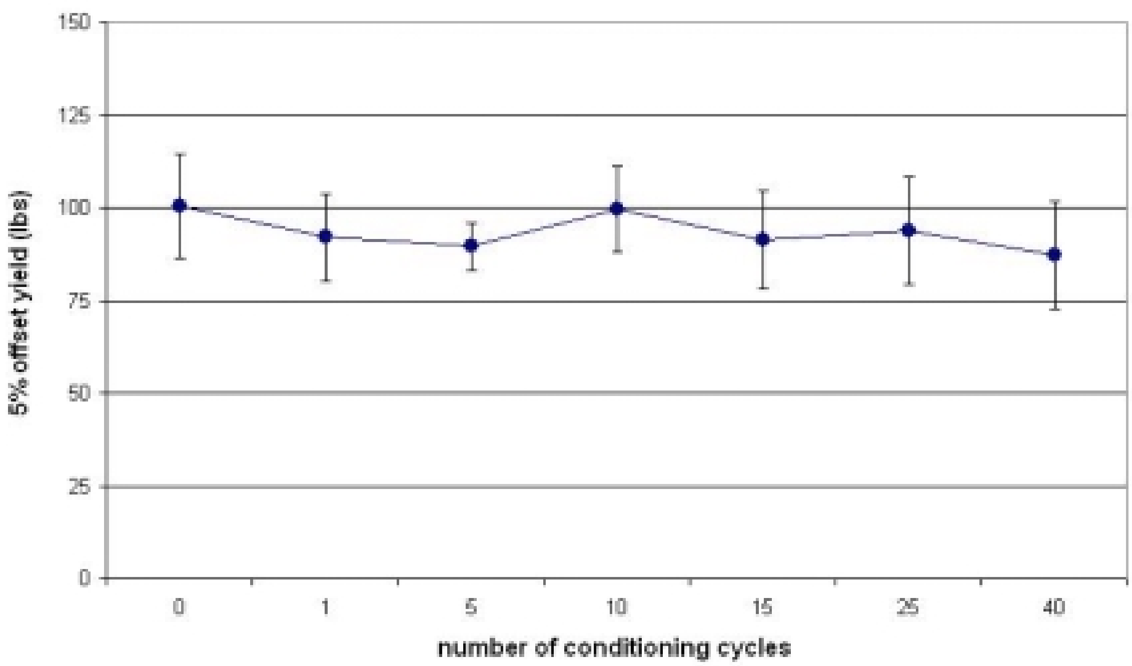


Figure 4.14: Observed 5% offset loads of 'Mill B' connections.

Table 4.18: Two tailed t-test results of 'Mill B' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	1.761	2.052	NO
1	5	0.707	2.074	NO
0	5	2.690	2.086	YES
5	10	2.939	2.074	YES
10	15	1.828	2.048	NO
10	25	1.230	2.052	NO
10	40	2.615	2.052	YES
25	40	1.249	2.048	NO

Table 4.19: Fisher's LSD results of 'Mill B' 5% offset yield values (95% CI).

Treatment (cycles)	0	10	25	1	15	5	40
mean:	100	100	94	92	91	90	87
grouping:	A	A	A	A	A		
			B	B	B	B	B

4.2.4 – Maximum Yield Performance

The maximum load performance exhibited by the 'Mill B' connections is seen in Figure 4.15. An initial reduction in average maximum load is observed between the control (0 cycles) and 1st cycle test results; however, the following cycle stages indicate an increasing effect. A p-value of <0.0001 undoubtedly describes significant differences among the means. A t-test identifies notable differences between the control group (0 cycles) and 1st cycle, the 1st and 25th, and the 15th and 25th cycle results (Table 4.20). In addition, Table 4.21 presents the output from Fisher's LSD procedure. The values are ordered chronologically in three groups, but show moderate similarities as each group overlaps the next.

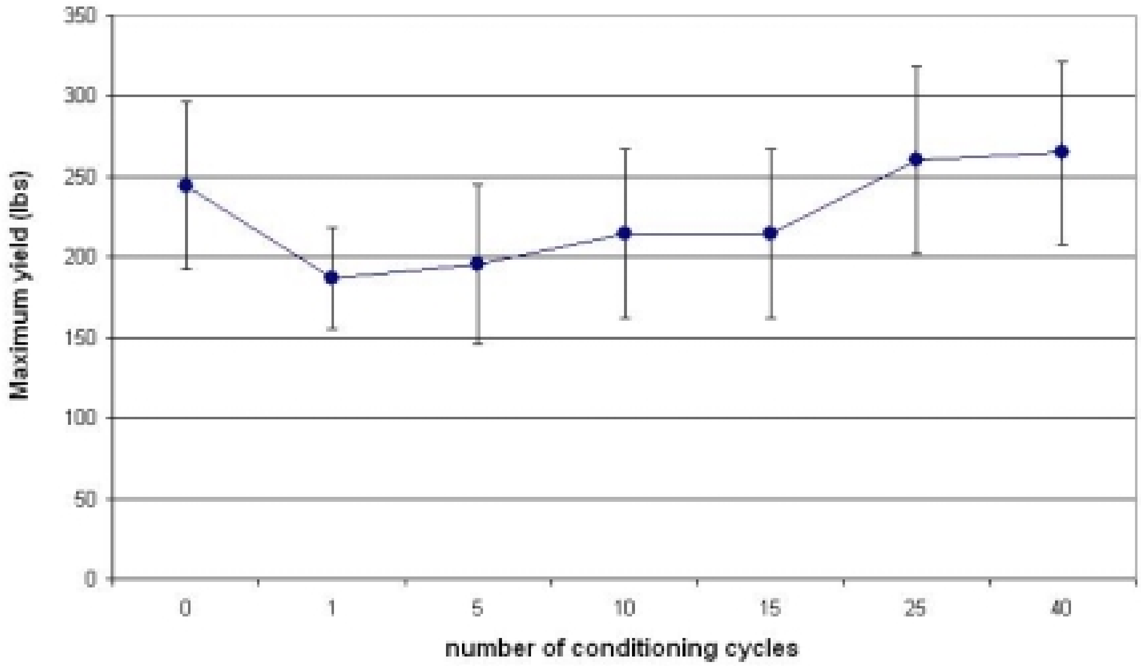


Figure 4.15: Observed maximum loads of 'Mill B' connections.

Table 4.20: Two tailed t-test results of 'Mill B' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	3.669	2.069	YES
1	5	0.566	2.064	NO
1	10	1.737	2.069	NO
1	15	1.749	2.069	NO
1	25	4.296	2.074	YES
15	25	2.254	2.048	YES
25	40	0.217	2.048	NO

Table 4.21: Fisher's LSD results of 'Mill B' maximum yield values (95% CI).

Treatment (cycles)	40	25	0	15	10	5	1
mean:	265	260	244	215	214	195	187
grouping:	A	A	A				
			B	B	B		
				C	C	C	C

The probability distribution of the maximum yield loads observed from 'Mill B' connections is shown in Figure 4.16. The corresponding scale and shape parameters are given in Table 4.22. An obvious change in the distribution observed at each cycle is clearly evident. The control and 1st cycle treatment groups produced test results with more central tendency than the other cycle groups. Connections receiving 5, 10, 15, 25, and 40 cycles of exposure showed more variation as expressed by the shorter height mounds, which are more spread out along the x-axis.

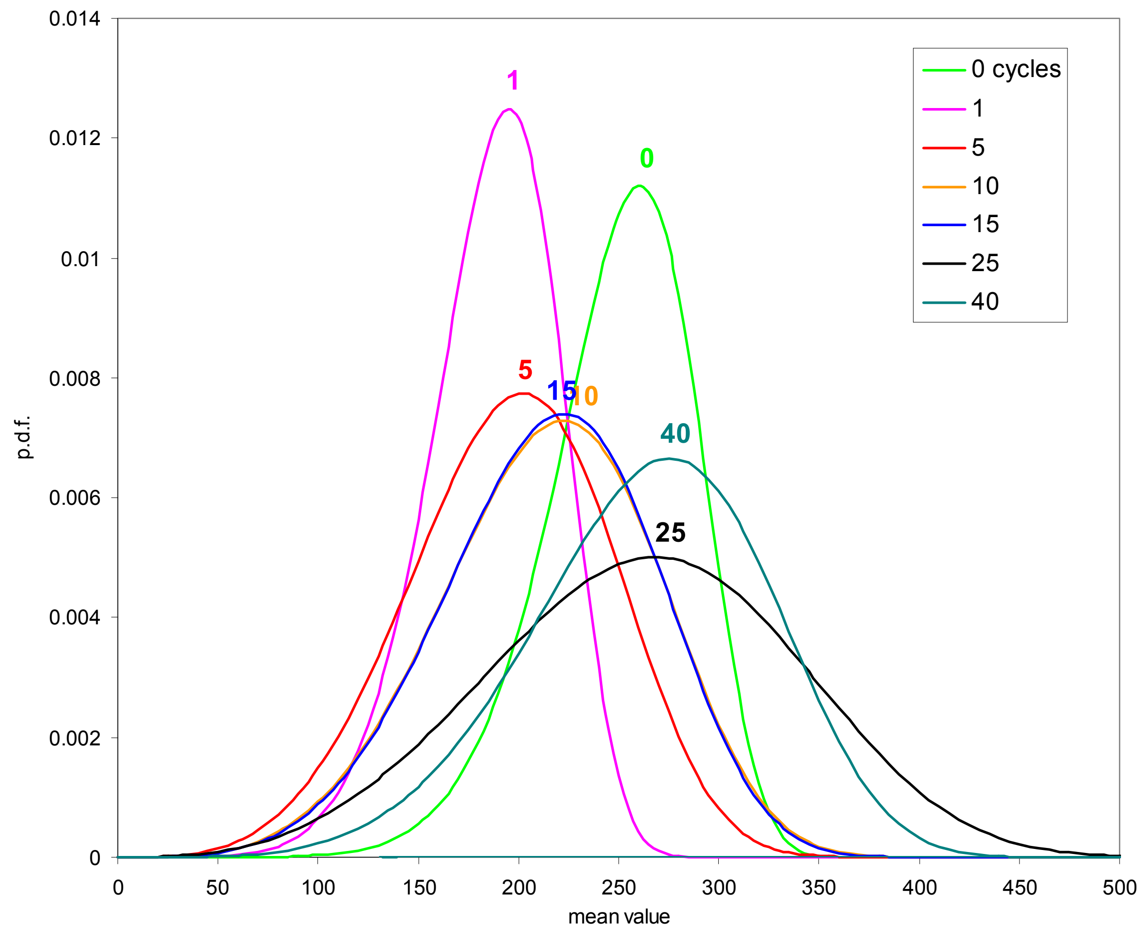


Figure 4.16: Probability density distributions of maximum yield loads for 'Mill B' connections (0-40 cycles).

Table 4.22: Weibull distribution parameters.

cycle:	**0**	**1**	**5**	**10**	**15**	**25**	**40**
scale, *a*	265.03	199.89	214.51	235.01	234.82	290.40	287.82
shape, *b*	8.02	6.70	4.39	4.53	4.61	3.81	5.10

4.2.5 – Failure Yield

The yield modes exhibited at failure for the 'Mill B' connections were limited to Modes III_m and III_s. Crushing within the main member, which caused Mode III_m failure yields, accounted for the majority of failure yields. Table 4.23 presents the percentage of connections exhibiting either Mode III_m or III_s yields at time of testing. Most connections, which failed because of main member crushing, did not exhibit any apparent damage to the side member as shown in Figure 4.17. Instead, wood crushing was observed adjacent to the nail's bearing surface within the main member.

Table 4.23: Yield modes observed at failure for 'Mill B' connections.

		0	1	5	10	15	25	40
Yield Mode	III_m	60.0%	86.7%	93.3%	80.0%	73.3%	73.3%	66.7%
	III_s	40.0%	13.3%	6.7%	20.0%	26.7%	26.7%	33.3%

Figure 4.17: Mode III_m failure of sample B4-11 (10 cycles).

Some connection tests were observed in which the heads of the nails rotated in a lateral direction during loading. This resulted in partial nail head embedment in the face of the side member material. This type of event normally only caused Mode III_m failures, but if the bearing resistance of the side member material was not sufficiently greater than that of the main member a Mode III_s yield would occur causing failure. Figure 4.18a and Figure 4.18b are photographs of connections in which the nail head embedment behavior progressed to a point where the entire nail was pulled through the OSB sheathing and produced Mode III_s failure yields.

(a) *(b)*

Figure 4.18: Mode III_s failures of samples B4-3 (10 cycles) and B7-12 (40 cycles).

4.2.6 – Density Analysis

Below, Figure 4.19 displays the mean density values of 'Mill B' type sheathing after 0 (control), 1, 5, 10, 15, 20, 25, and 30 cycles. Initially decreasing, the values increase slightly between the 1st and 5th readings, but return to a decreasing trend as cycling progresses toward 30 cycles.

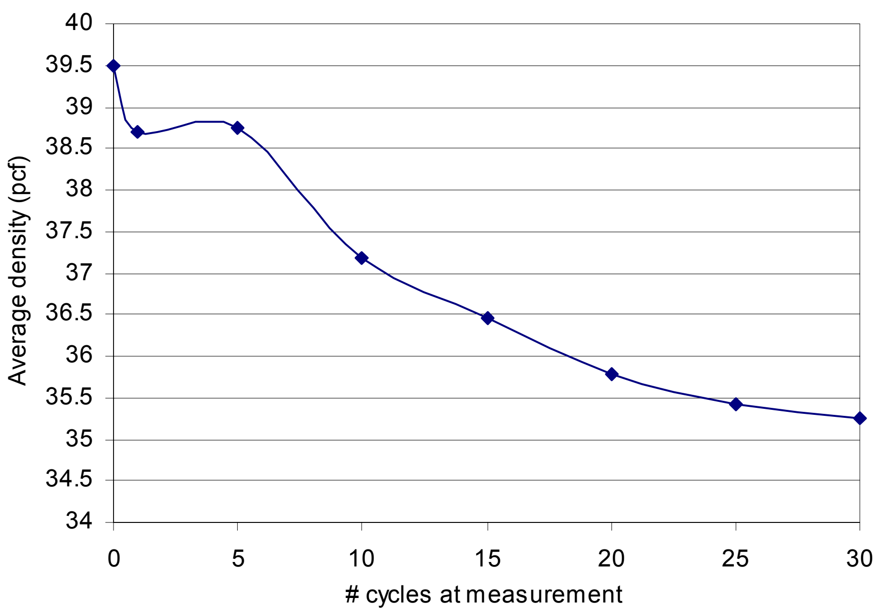


Figure 4.19: Average density of 'Mill B' sheathing.

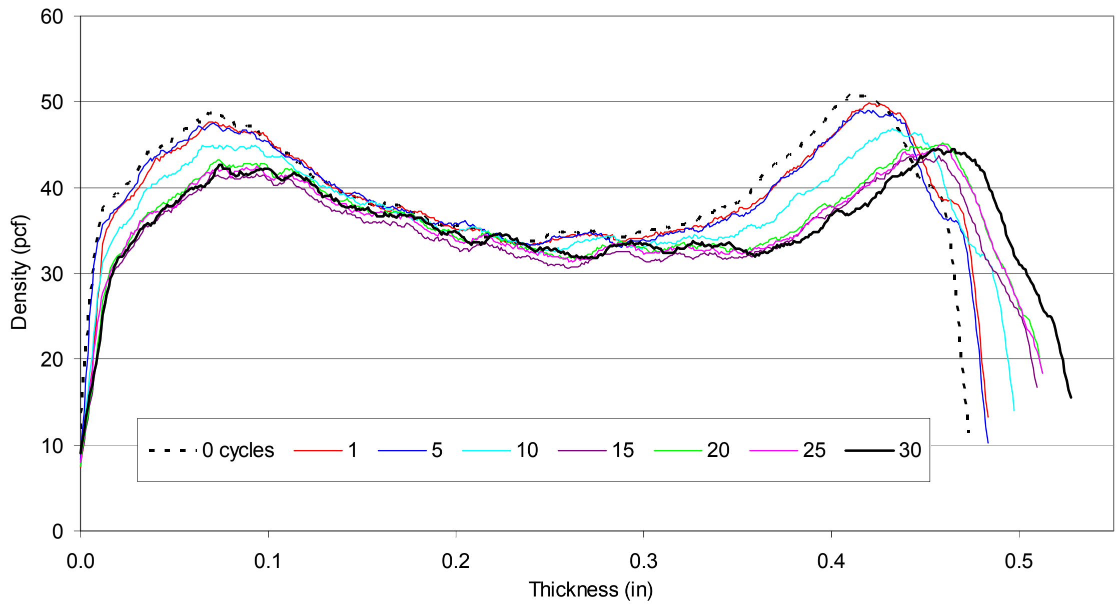


Figure 4.20: Overlay of 'Mill B' vertical-density profiles.

Above, Figure 4.20 illustrates how density changed across the thickness of 'Mill B' type sheathing during cycling. The dense face layers show evidence of more de-densification as cycling increases when compared to the central core region. This is consistent with expectations as the denser face layers contain more material and therefore, more interfaces susceptible to deterioration. Unrecoverable thickness swell is also apparent, which reaches 12.1% in relation to the original measurement. Table 4.24 shows the relative and cumulative density changes observed at each cycle.

Table 4.24: Relative and cumulative changes in thickness of 'Mill B' sheathing.

		# cycles at measurement						
		1	5	10	15	20	25	30
Mill B	Vs. previous	2.2%	-0.5%	3.4%	2.8%	0.8%	0.1%	2.8%
	Vs. control	2.2%	1.7%	5.2%	8.1%	9.0%	9.1%	12.1%

4.2.7 – Yield Model Estimation

Summarizations of the parameters used in the general dowel equations are given in Table 4.25. Following the recommendations for treatment of dowel bearing length, the fastener tip was not included in the calculations (1.8 in. instead of 2.0 in.). The 5% offset loads observed in 'Mill B' connections were compared to the 5% offset yield estimates of the yield model. Predicted values were computed using non-cycled materials. Table 4.26 provides comparisons made with the results from each cycled group of connections. At the 5% offset, a Mode III_s yield and 94 lb. load was determined by the model. The yield mode differs from the yield mode observed at failure (Mode III_m) because the general dowel equations only estimate the mode at yield. All calculated values involve bearing resistance parameters evaluated at the 5% offset. The predicted vs. observed ratios (P/O) indicate similarities with all treatment groups. This concurs with the earlier examination of 'Mill B' 5% offset results, as no definite trend was evident as cycling time increased.

Table 4.25: Yield model input parameters for 'Mill B' connection components.

Main Member			Side Member			Fastener		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.32	2405	12.0%	0.48	3723	16.1%	0.113	41.3	4.1%

Table 4.26: Comparisons of observed vs. predicted 5% offset loads for 'Mill B' connections.

	Observed		Predicted		P/O
conditioning cycles	mean (lb)	COV	(lb)	yield	
0 (control)	100	14.0%	94	Mode III_s	94%
1	92	12.7%			102%
5	90	7.3%			104%
10	100	11.7%			94%
15	91	14.4%			103%
25	94	15.5%			100%
40	87	16.6%			108%

4.3 – 'Mill C' Connections

'Mill C' connections were made from stud grade SF main members and 7/16 in. OSB side members. A 6d uncoated nail was used as the fastener. Table 4.27 provides summary statistics for observed performance parameters during all cycling stages. This connection configuration afforded a maximum yield near 345 lbs. at about 0.6 to 0.8 in. of slip. The elastic stiffness values show considerable variability at all cycles. Some tests values related the 5% offset load also exhibited a large COV. Figure 4.21 depicts the load/slip plot of sample C3-4, which is similar to other 'Mill C' connections.

Table 4.27: Observed metrics and predictions of 'Mill C' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (C1)	mean	7380	94	253	93.3%	6.7%
	COV	41.7%	16.7%	17.5%		
1 cycle (C2)	mean	6332	91	212	100.0%	0.0%
	COV	29.5%	16.2%	21.9%		
5 cycles (C3)	mean	6265	90	219	85.7%	14.3%
	COV	56.1%	14.1%	26.2%		
10 cycles (C4)	mean	6155	105	274	100.0%	0.0%
	COV	46.5%	20.0%	25.8%		
15 cycles (C5)	mean	5434	111	304	86.7%	13.3%
	COV	51.4%	17.4%	15.3%		
25 cycles (C6)	mean	3915	106	316	53.3%	46.7%
	COV	30.4%	18.6%	16.8%		
40 cycles (C7)	mean	4870	92	345	40.0%	60.0%
	COV	38.2%	27.3%	13.9%		
Yield Model Prediction	**Lateral Resistance (lb)**		**95**			
	Yield Mode		III_s			

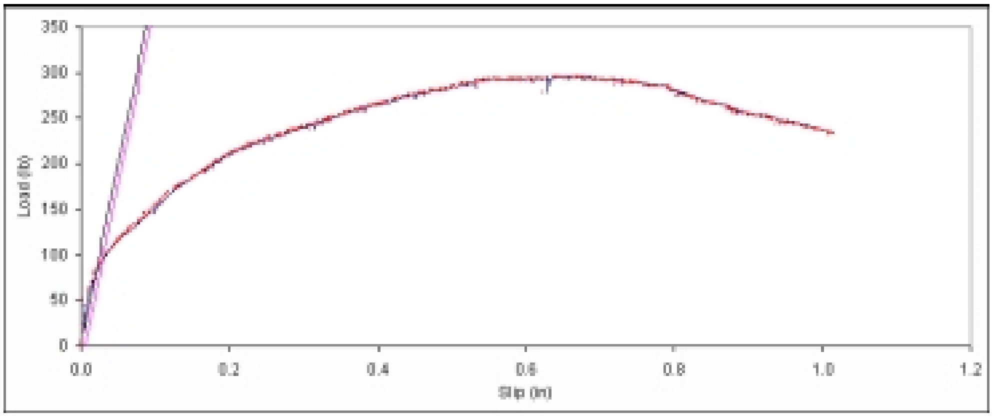


Figure 4.21: Typical load/slip plot of a 'Mill C' connection (sample C3-4).

4.3.1 – Moisture Contents and Specific Gravities

As shown below in Table 4.28, main member mean MC values were 11.22% with a 4.9% overall COV. Side members, as in other connection groups, were drier at time of testing with mean MC values at 9.13% and 8.8% COV. SG values were 0.35 for the main members and 0.65 for the side member materials with 2.0% and 4.2% COV values, respectively.

Table 4.28: Moisture content (at testing) and specific gravity values of 'Mill C' connection components.

	Main Member				Side Member			
	% moisture content		specific gravity		% moisture content		specific gravity	
conditioning cycles	mean	COV	mean	COV	mean	COV	mean	COV
0	12 *	---	0.35	8.8%	12 *	---	0.62	4.6%
1	10.3	3.6%	0.35	8.6%	7.8	1.8%	0.63	4.5%
5	11.4	2.6%	0.35	6.9%	8.9	6.5%	0.68	3.3%
10	11.6	2.3%	0.34	4.9%	9.2	4.2%	0.68	6.1%
15	11.9	4.9%	0.35	5.7%	10.2	3.6%	0.67	8.6%
25	11.2	3.9%	0.34	8.5%	9.2	1.0%	0.65	8.0%
40	11.0	4.3%	0.36	6.8%	9.5	3.2%	0.62	4.8%
Overall	**11.2**	**4.9%**	**0.35**	**2.0%**	**9.1**	**8.8%**	**0.65**	**4.2%**

** Zero cycle connections (controls) assumed 12% MC.*

4.3.2 – Elastic Stiffness Performance

The performance of 'Mill C' connections, in terms of elastic stiffness, seems to show a decreasing effect as cyclic humidity conditioning continued to 40 cycles. This is seen in Figure 4.22. Significant differences among mean values are indicated by a p-value of 0.0106. The specific location of the substantial variations in elastic stiffness occur between the 0 and 25th cycle periods as shown in the t-test performed for a 95% CI (Table 4.29). Fisher's LSD points toward three overlapping groupings of ordered results (Table 4.30). Although the boundaries of groupings are not distinct, a trend is seen as the elastic stiffness values decrease slowly until the 25th cycle and then rise slightly, but not significantly, in the last measurement at 40th cycles. As experienced with other connection types, the variability in elastic stiffness values causes difficulty when making inferences.

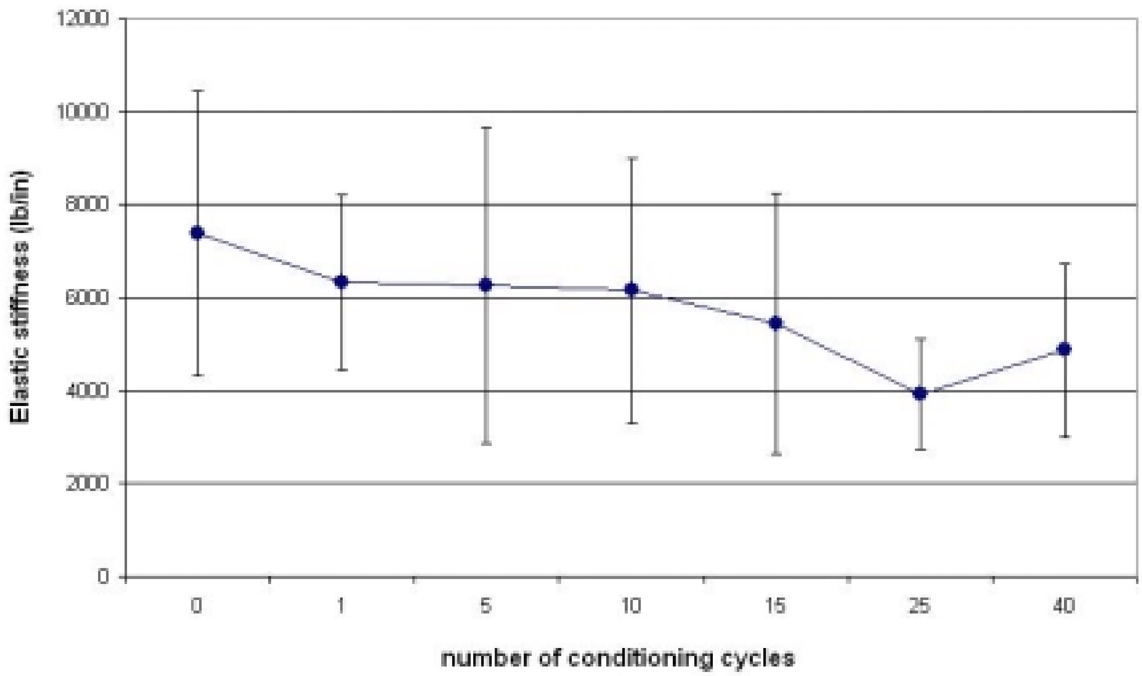


Figure 4.22: Observed elastic stiffness values of 'Mill C' connections.

Table 4.29: Two tailed t-test results of 'Mill C' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	1.127	2.069	NO
1	5	0.068	2.074	NO
0	5	0.944	2.048	NO
0	10	1.130	2.048	NO
0	15	1.814	2.048	NO
0	25	4.069	2.101	YES
15	25	1.936	2.093	NO
25	40	1.673	2.064	NO

Table 4.30: Fisher's LSD results of 'Mill C' elastic stiffness values (95% CI).

Treatment (cycles)	0	1	5	10	15	40	25
mean:	7380	6332	6265	6155	5434	4870	3915
grouping:	A	A	A	A			
		B	B	B	B	B	
					C	C	C

4.3.3 – 5% Offset Yield Performance

As shown in Figure 4.23, the 5% offset yield performance of 'Mill C' connections is initially unchanged until after the 5th cycle when the results begin to increase. They peak is at the 15th cycle and then a decrease to observed through the 40th cycle, which has a mean value significantly identical to the control results, as reported by the two-tail t-test (Table 4.31). A p-value of 0.0083 indicates a significant difference among the mean values, which are described as being between the connection groups receiving 0 cycles (control) and 15 cycles. Also, the 15th and 40th cycles are stated to be statistically different, based upon a 95% CI. Supporting the claims of the t-test, Fisher's LSD test reports that four groupings exist among the datasets (Table 4.32).

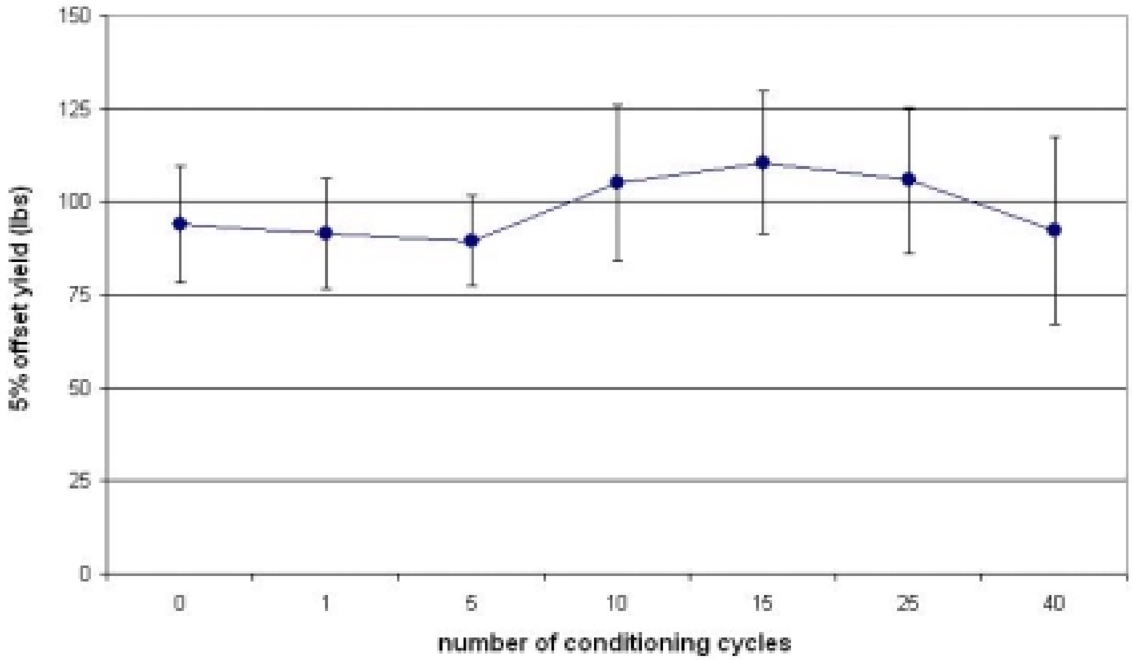


Figure 4.23: Observed 5% offset loads of 'Mill C' connections.

Table 4.31: Two tailed t-test results of 'Mill C' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.431	2.048	NO
1	5	0.362	2.052	NO
0	5	0.819	2.056	NO
0	10	1.647	2.056	NO
0	15	2.633	2.052	YES
10	15	0.775	2.048	NO
15	25	0.680	2.048	NO
15	40	2.223	2.056	YES
25	40	1.618	2.056	NO

Table 4.32: Fisher's LSD results of 'Mill C' 5% offset yield values (95% CI).

Treatment (cycles)	15	25	10	0	40	1	5
mean:	111	106	105	94	92	91	90
grouping:	A	A	A				
		B	B	B	B		
			C	C	C	C	
				D	D	D	D

4.3.4 – Maximum Yield Performance

Figure 4.24 illustrates the trend observed from the maximum yield loads of 'Mill C' connections. Initially, the mean values drop considerably from the control sample results, but after leveling off from the 1st to 5th cycles, they begin to increase through the last tests performed at 40 cycles. A p-value of <0.0001 provides convincing evidence that substantial differences exist. Table 4.33 declares the significant differences as being between the loads observed in the control and 1st cycles, the 5th and 10th cycles, and between the 15th and 40th cycles. Fisher's LSD follows the obvious trend in its assignments of groupings (Table 4.34). The numerical sequencing closely mimics the chronological order with the highest maximum loads seen in the more exposed connection samples.

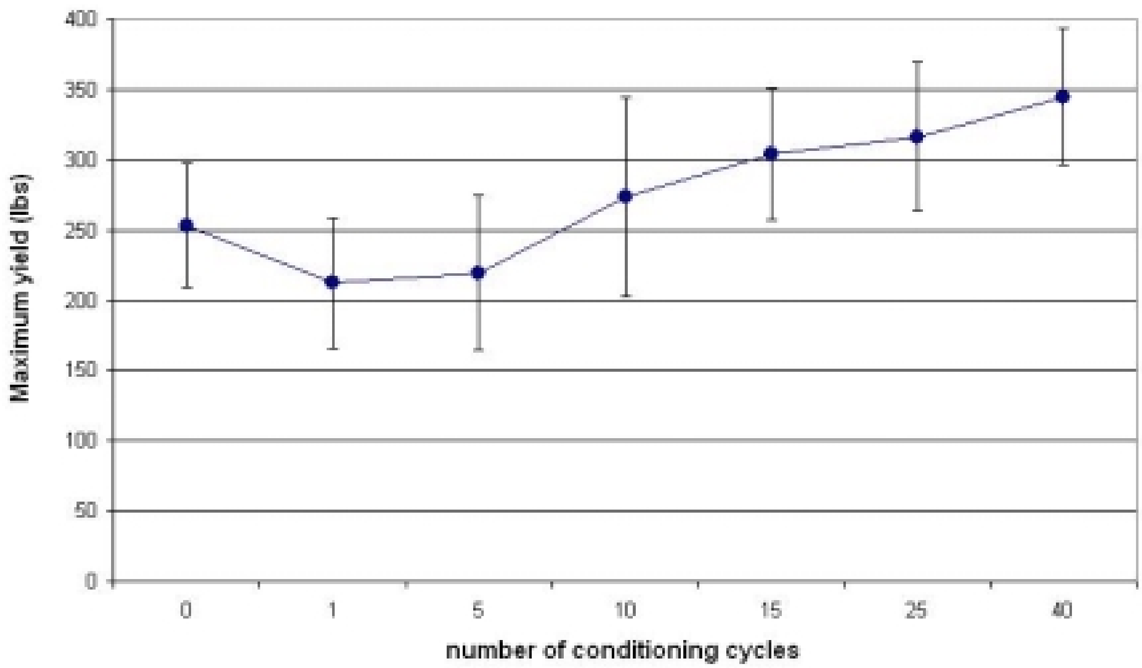


Figure 4.24: Observed maximum loads of 'Mill C' connections.

Table 4.33: Two tailed t-test results of 'Mill C' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	2.476	2.048	YES
1	5	0.399	2.052	NO
1	10	2.831	2.064	YES
5	10	2.346	2.056	YES
10	15	1.395	2.064	NO
10	25	1.866	2.056	NO
10	40	3.221	2.060	YES
25	40	1.542	2.048	NO
15	40	2.348	2.048	YES

Table 4.34: Fisher's LSD results of 'Mill C' maximum yield values (95% CI).

Treatment (cycles)	40	25	15	10	0	5	1
mean:	345	316	304	274	253	219	212
grouping:	A	A					
		B	B				
			C	C			
				D	D		
					E	E	
						F	F

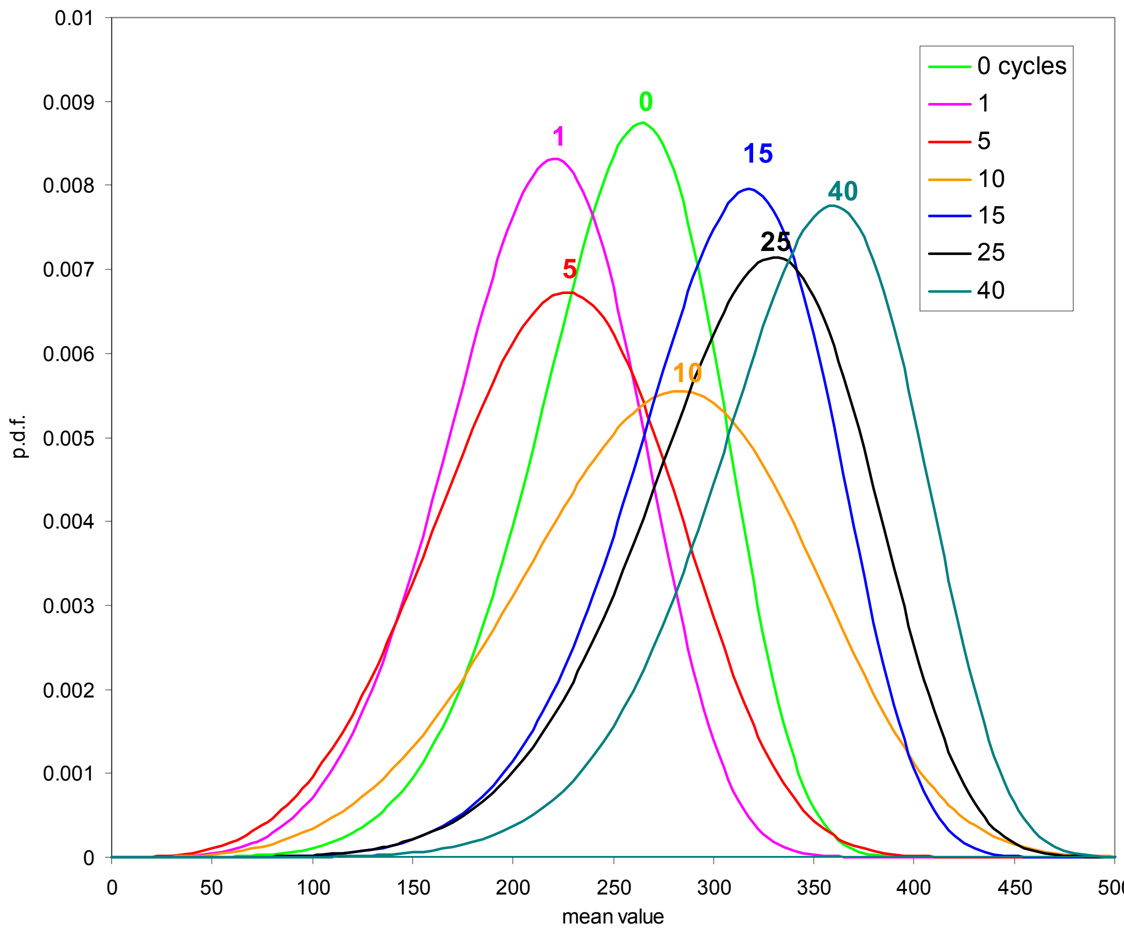


Figure 4.25: Probability density distributions of maximum yield loads for 'Mill C' connections (0-40 cycles).

Table 4.35: Weibull distribution parameters.

cycle:	**0**	**1**	**5**	**10**	**15**	**25**	**40**
scale, *a*	271.47	230.31	241.31	300.23	324.98	339.03	366.33
shape, *b*	6.37	5.10	4.29	4.41	6.95	6.51	7.66

The probability distribution of the maximum loads observed from 'Mill C' connections is given in Figure 4.25 and related parameters are presented in Table 4.35. Very little differences are seen among the shape and sizes of the mounds. Aside from the shifts along the x-axis, the 5th and 10th cycle distributions are the lowest and most spread out with less central tendency as seen in the control, 1st, 15th, 25th, and 40th cycle results.

4.3.5 – Failure Yield

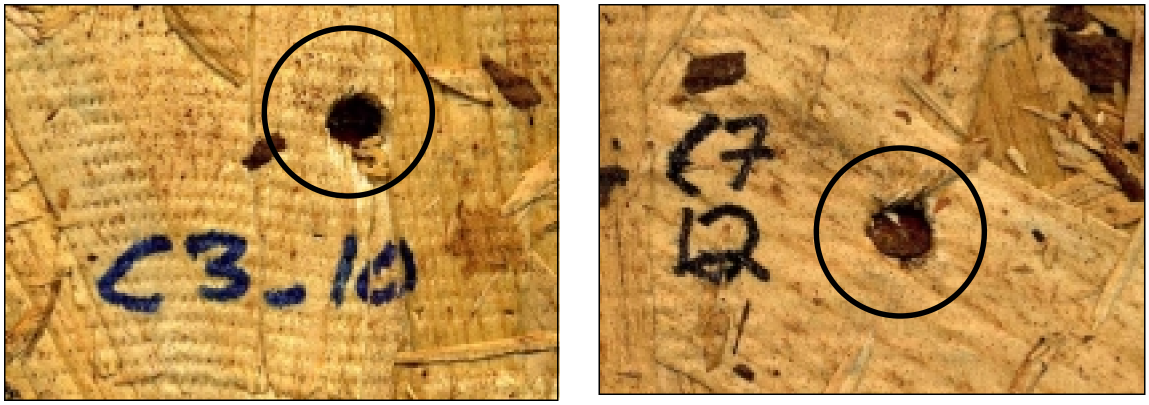
Like the other connection configurations discussed previously, the yield modes observed at failure for the 'Mill C' connections were limited to Modes III_m and III_s. Mode III_m failure yields were mostly seen, but as the periods of cyclic relative humidity increased the occurrence of Mode III_s failure yields also increased. Table 4.36 is a listing of the percentages of connections exhibiting either Mode III_m or III_s yields at time of testing.

Table 4.36: Yield modes observed at failure for 'Mill C' connections.

		0	1	5	10	15	25	40
Yield Mode	III_m	93.3%	100.0%	85.7%	100.0%	86.7%	53.3%	40.0%
	III_s	6.7%	0.0%	14.3%	0.0%	13.3%	46.7%	60.0%

Primarily, connections failed because of main member crushing (Mode III_m) and did not exhibit any noticeable damage to the side member as shown in Figure 4.26. Connections that failed by Mode III_s often progressed from Mode III_m to III_s because of a previously noted behavior where lateral rotation of the nail was permitted within the side member material and nail pull-through eventually occurred. This is shown in Figure 4.27.

Figure 4.26: Mode III_m failure of sample C7-10 (40 cycles).



(a) *(b)*

Figure 4.27: Mode III_s failure of samples C3-10 (5 cycles) and C7-12 (40 cycles).

4.3.6 – Density Analysis

The mean density values observed in 'Mill C' type sheathing samples is shown in Figure 4.28. The values increase slightly between the control (0 cycles) and 1st cycle readings, but a decreasing trend continued as conditioning progressed toward 30 cycles.

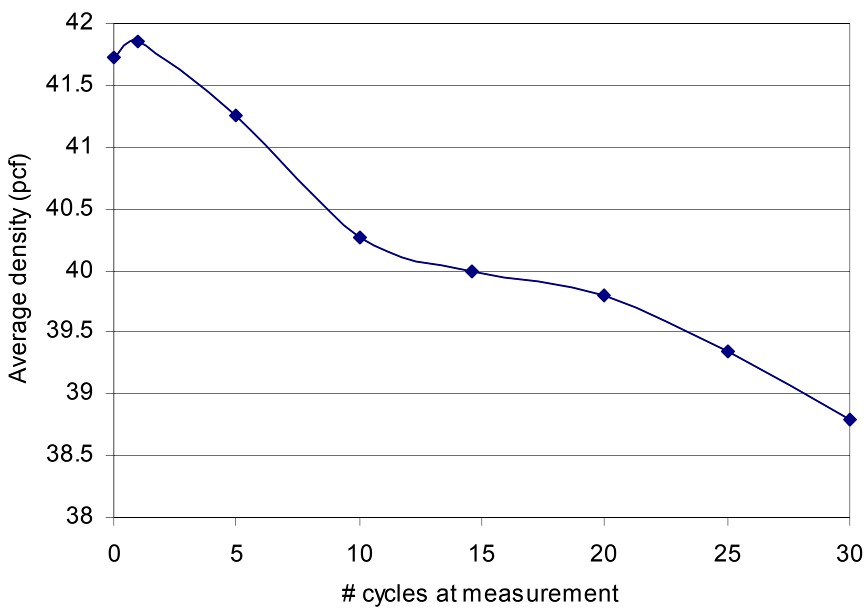


Figure 4.28: Average density of 'Mill C' sheathing.

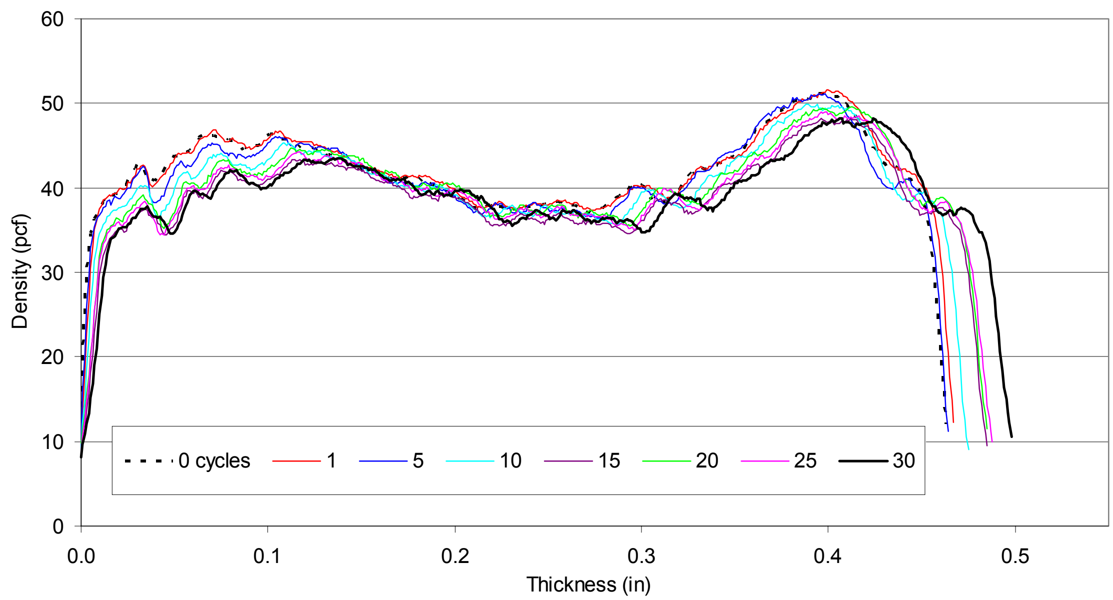


Figure 4.29: Overlay of 'Mill C' vertical-density profiles.

Figure 4.29, above, illustrates how the density changed across the thickness of 'Mill C' type sheathing samples during cycling. The dense face layers show more rapid de-densification as cycling increased in comparison to the central core region. Unrecoverable thickness swell is also apparent, which reached 7.6% in relation to the original measurement. Table 4.37 shows the relative and cumulative density changes between measurements.

Table 4.37: Relative and cumulative changes in thickness of 'Mill C' sheathing.

		# cycles at measurement						
		1	**5**	**10**	**15**	**20**	**25**	**30**
Mill C	Vs. previous	0.8%	-0.7%	2.3%	2.2%	0.3%	0.3%	2.3%
	Vs. control	0.8%	0.0%	2.3%	4.5%	4.9%	5.2%	7.6%

4.3.7 – Yield Model Estimation

The experimental data required in the yield model calculations is depicted in Table 4.38. The dowel length used in these calculations is less than the actual fastener measurement (1.8 in. instead of 2.0 in.) in order to exclude effect of the nail's diamond pointed tip. This follows the guidelines stated in *General dowel equations for calculating lateral connection values – Technical Report 12* (AF&PA 1999). The 5% offset loads observed in 'Mill C' connection tests were compared to the 5% offset yield calculated using the general dowel equations. Estimated values were determined using non-cycled main and side member materials (conditioned to 12% MC prior to testing) and therefore, are most analogous to the 0 cycle (control) connections. As shown in Table 4.39, comparisons were made with the results from each treatment group. A Mode III_s yield was estimated with a load of 95 lbs. at the 5% offset. The mode is different from what was reported at failure (Mode III_m) as the general dowel equations only estimate the mode at yield. The predicted vs. observed ratios (P/O) show likenesses among all treatment groups, as the 5% offset load values demonstrated an overall unchanging trend in previous analysis.

Table 4.38: Yield model input parameters for 'Mill C' connection components.

Main Member			**Side Member**			**Fastener**		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.32	2405	12.0%	0.48	3815	18.4%	0.113	41.3	4.1%

Table 4.39: Comparisons of observed vs. predicted 5% offset loads for 'Mill C' connections.

		Observed		**Predicted**		**P/O**
		mean (lb)	COV	(lb)	yield	
conditioning cycles	0 (control)	94	16.7%	95	Mode III_s	101%
	1	91	16.2%			104%
	5	90	14.1%			106%
	10	105	20.0%			90%
	15	111	17.4%			86%
	25	106	18.6%			90%
	40	92	27.3%			103%

4.4 – 'Mill D' Connections

'Mill D' connections were made from SF stud grade main members, 7/16 in. OSB side members, and 6d uncoated wire nails. Table 4.40 shows summary statistics for observed 'Mill D' connection performance parameters. This connection allowed for uppermost maximum yield values of 325 lbs. Again, the COV values of the elastic stiffnesses were large. Figure 4.30 is the load/slip plot of sample D4-1, which is typical of nearly all 'Mill D' connections.

Table 4.40: Observed metrics and predictions of 'Mill D' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (D1)	mean	9127	110	249	80.0%	20.0%
	COV	53.5%	19.3%	20.3%		
1 cycle (D2)	mean	5127	93	191	100.0%	0.0%
	COV	51.3%	21.4%	21.1%		
5 cycles (D3)	mean	5715	86	217	66.7%	33.3%
	COV	55.1%	25.4%	23.2%		
10 cycles (D4)	mean	3995	110	259	86.7%	13.3%
	COV	49.4%	19.2%	17.4%		
15 cycles (D5)	mean	4560	83	286	46.7%	53.3%
	COV	27.3%	24.7%	16.7%		
25 cycles (D6)	mean	4240	100	317	60.0%	40.0%
	COV	34.6%	19.0%	15.3%		
40 cycles (D7)	mean	4493	92	326	46.7%	53.3%
	COV	25.7%	10.5%	9.2%		
Yield Model Prediction	**Lateral Resistance (lb)**	**96**				
	Yield Mode	**III_s**				

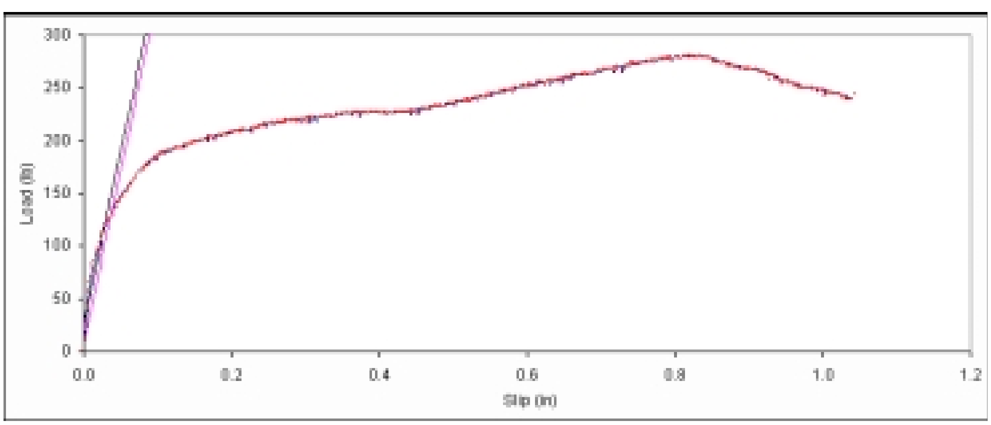


Figure 4.30: Typical load/slip plot of a 'Mill D' connection (sample D4-1).

4.4.1 – Moisture Contents and Specific Gravities

In regards to the 'Mill D' connection specimens, the main member mean MC values were 11.42% with a 5.2% overall COV and side member components contained less moisture at testing with mean MC values at 9.64% and 10.9% COV. Specific gravity values were 0.35 for the main members and 0.65 for the side member materials with 2.9% and 2.3% COV values, respectively. Table 4.41 further describes the moisture content and specific gravity information.

Table 4.41: Moisture content (at testing) and specific gravity values of 'Mill D' connection components.

	Main Member				Side Member			
	% moisture content		specific gravity		% moisture content		specific gravity	
conditioning cycles	mean	COV	mean	COV	mean	COV	mean	COV
0	12 *	---	0.34	7.8%	12 *	---	0.67	9.0%
1	11.1	7.3%	0.34	7.9%	8.2	2.1%	0.64	9.7%
5	10.8	2.5%	0.36	4.4%	9.3	5.4%	0.64	7.0%
10	11.5	5.3%	0.35	4.6%	10.0	6.2%	0.65	4.3%
15	12.5	6.0%	0.37	6.7%	11.4	3.3%	0.66	6.3%
25	11.4	3.2%	0.35	8.4%	9.6	1.4%	0.62	8.6%
40	11.2	4.4%	0.36	6.2%	9.5	2.9%	0.65	5.1%
Overall	**11.4**	**5.2%**	**0.35**	**2.9%**	**9.6**	**10.9%**	**0.65**	**2.3%**

** Zero cycle connections (controls) assumed 12% MC.*

4.4.2 – Elastic Stiffness Performance

As illustrated in Figure 4.31, the elastic stiffness values from the 'Mill D' connections appear to decrease a large amount after the control reading (0 cycle) and then level out as the 40th cycle is approached. A p-value of <0.0001 provides evidence of significantly different mean values and the t-test states the disparity to be between the control and 1st cycle test results (Table 4.42). Additionally, Fisher's LSD procedure, depicted in Table 4.43, resolves two distinct groupings of the data. The control reading is isolated from the 1st through 40th cycle readings, as the t-test also identified no significant differences among the last six test results.

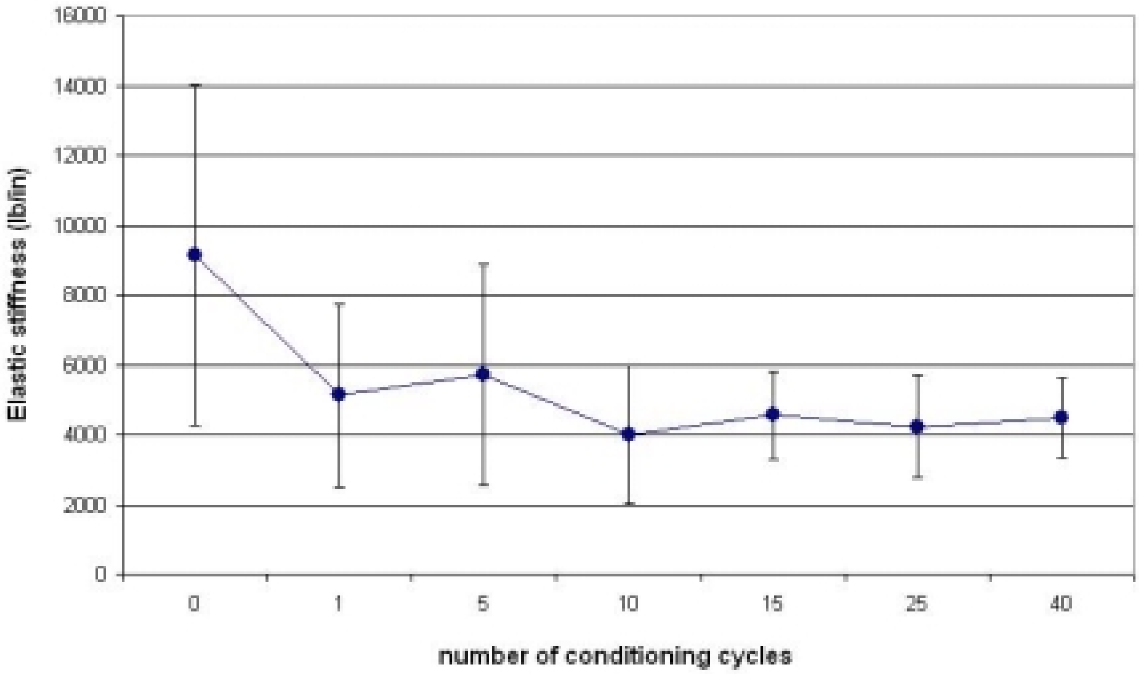


Figure 4.31: Observed elastic stiffness values of 'Mill D' connections.

Table 4.42: Two tailed t-test results of 'Mill D' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	2.793	2.080	YES
1	5	0.555	2.052	NO
1	10	1.333	2.056	NO
1	15	0.754	2.086	NO
1	25	1.142	2.074	NO
1	40	0.855	2.093	NO

Table 4.43: Fisher's LSD results of 'Mill D' elastic stiffness values (95% CI).

Treatment (cycles)	0	5	1	15	40	25	10
mean:	9127	5715	5127	4560	4493	4240	3995
grouping:	A	B	B	B	B	B	B

4.4.3 – 5% Offset Yield Performance

The 5% offset yield performance of 'Mill D' connections is inconclusive. As seen in Figure 4.32, the initial trend is decreasing, but then increases at the 10^{th} cycle to a magnitude equivalent to the control results. In subsequent cycles, the values decrease once more and then increase slightly in the last test observations. A 0.0004 p-value suggests significant differences among the treatment means. The two-tailed t-test reports dissimilarities between each sequential cycle results, with an exception for the 1^{st} and 5^{th} cycles, which are statistically alike (Table 4.44). Differences between the 25^{th} and 40^{th} cycles are also not detectable. The grouping order specified by Fisher's LSD procedure does not follow the chronological order of testing, but instead clusters the cycles according to their relative magnitude with overlapping groups (Table 4.45).

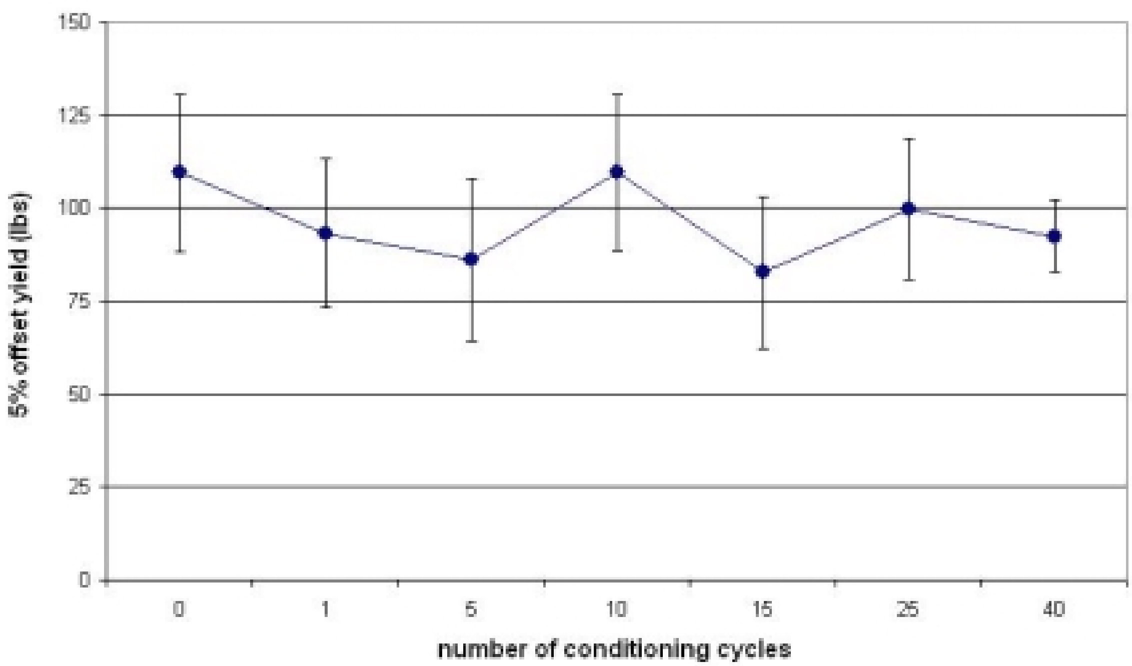


Figure 4.32: Observed 5% offset loads of 'Mill D' connections.

Table 4.44: Two tailed t-test results of 'Mill D' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	2.163	2.048	YES
1	5	0.936	2.048	NO
1	10	2.200	2.048	YES
5	10	3.016	2.048	YES
10	15	3.579	2.048	YES
15	25	2.387	2.048	YES
25	40	1.334	2.080	NO

Table 4.45: Fisher's LSD results of 'Mill D' 5% offset yield values (95% CI).

Treatment (cycles)	10	0	25	1	40	5	15
mean:	110	110	100	93	92	86	83
grouping:	A	A	A				
			B	B	B	B	
				C	C	C	C

4.4.4 – Maximum Yield Performance

The maximum load performance of 'Mill D' connections is depicted in Figure 4.33. After the control test results, the mean values initially decreased and then slowly increased continuously as cycling progressed. An ANOVA p-value of <0.0001 clearly indicates significant differences among the treatment mean values. Furthermore, the t-test specifically denotes the disparities between the cycle results (Table 4.46). No differences are found between the 1st and 5th cycles, the 10th and 15th cycles, or the 25th and 40th cycles. The Fisher's LSD test produces overlapping groups, which are primarily arranged in chronological order as load values mostly increased as cycling continued (Table 4.47).

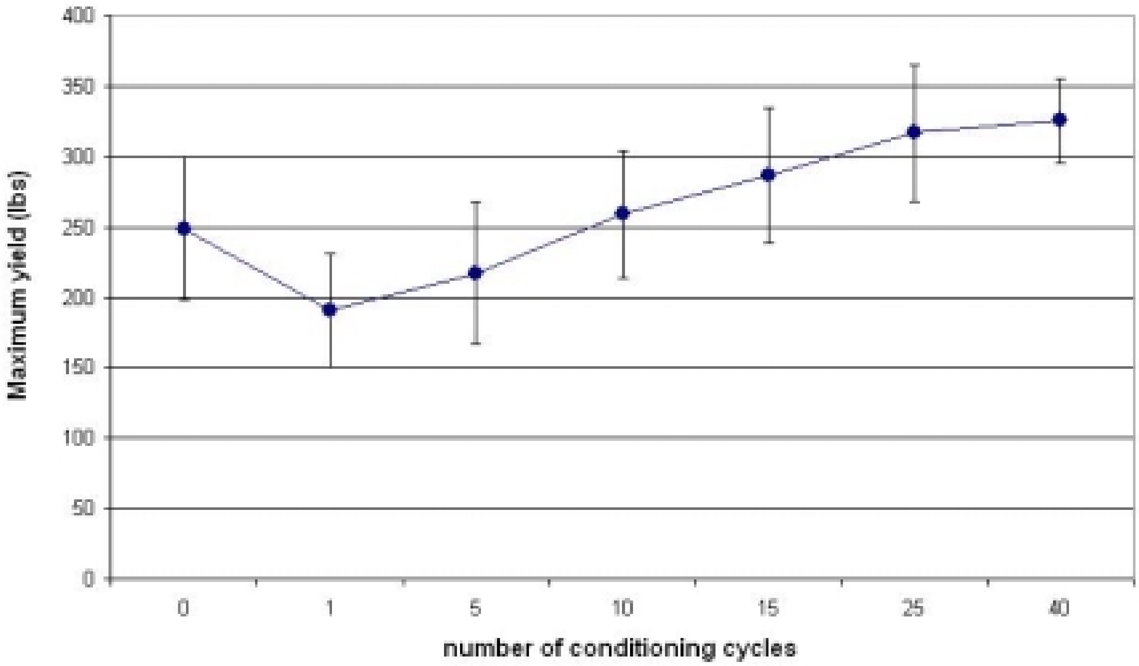


Figure 4.33: Observed maximum loads of 'Mill D' connections.

Table 4.46: Two tailed t-test results of 'Mill D' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	3.485	2.052	YES
1	5	1.590	2.052	NO
1	10	4.387	2.048	YES
5	10	2.407	2.048	YES
10	15	1.597	2.048	NO
10	25	3.368	2.048	YES
15	25	1.733	2.048	NO
25	40	0.605	2.069	NO

Table 4.47: Fisher's LSD results of 'Mill D' maximum yield values (95% CI).

Treatment (cycles)	40	25	15	10	0	5	1
mean:	326	317	286	259	249	217	191
grouping:	A	A					
		B	B				
			C	C			
				D	D		
					E	E	
						F	F

The probability distribution of the maximum loads observed from 'Mill D' connections is shown in Figure 4.34 and Table 4.48 provides the scale and shape parameters used. The distribution of the 1st cycle results display more central tendency than the others, which appear to all have similar height, but shift positively along the x-axis. As discussed in the previous paragraph and seen in Figure 4.33, there is an increasing effect in maximum load as cycling continues.

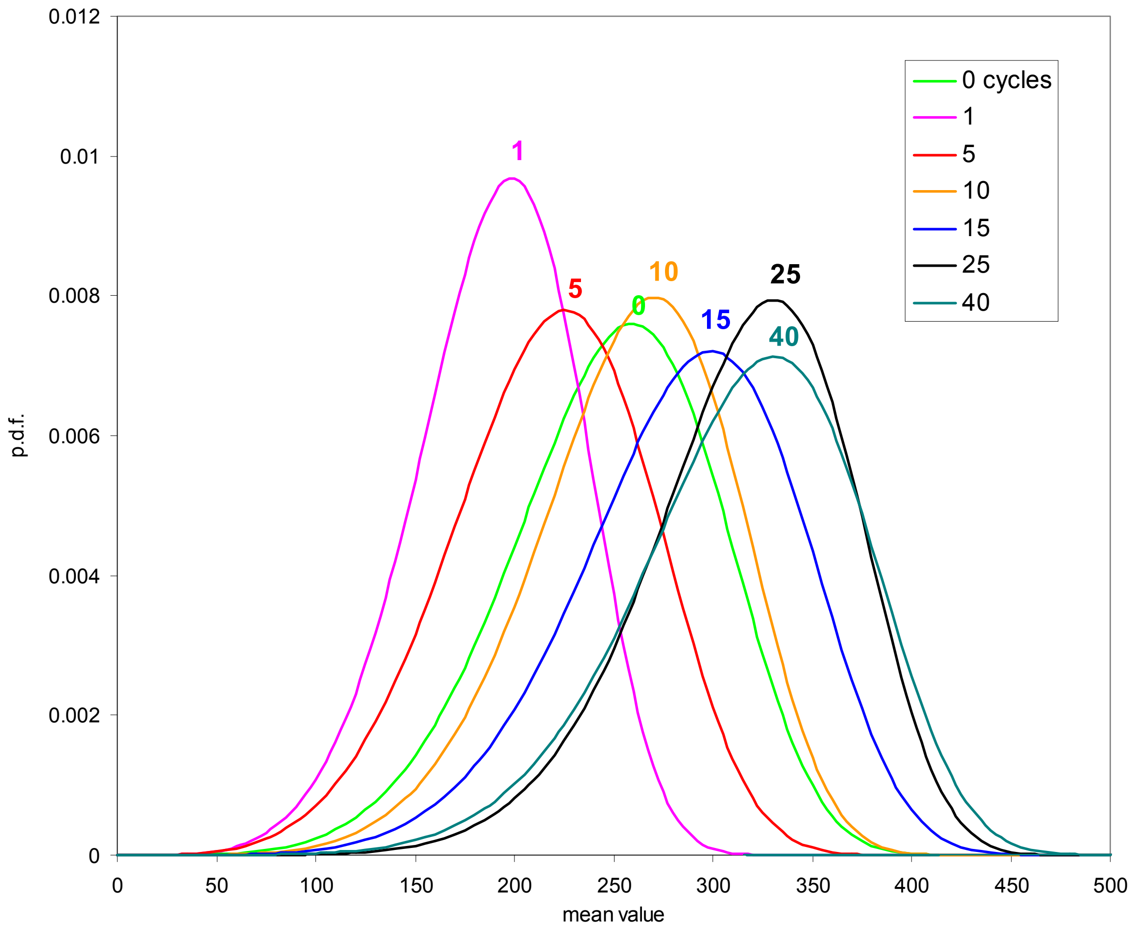


Figure 4.34: Probability density distributions of maximum yield loads for 'Mill D' connections (0-40 cycles).

Table 4.48: Weibull distribution parameters.

cycle:	0	1	5	10	15	25	40
scale, ***a***	269.45	206.73	236.47	279.23	308.72	337.55	339.34
shape, ***b***	5.47	5.34	4.90	5.96	5.96	7.21	6.50

4.4.5 – Failure Yield

'Mill D' connections exhibited both Mode III_m and Mode III_s yields at the point of failure. Larger portions of the Mode III_m were observed in the less cycled samples, but as exposure to cyclic humidity conditioning increased the proportions of Mode III_s yields also increased (Table 4.49).

Table 4.49: Yield modes observed at failure for 'Mill D' connections.

		0	1	5	10	15	25	40
Yield Mode	III_m	80.0%	100.0%	66.7%	86.7%	46.7%	60.0%	46.7%
	III_s	20.0%	0.0%	33.3%	13.3%	53.3%	40.0%	53.3%

Most connections, which received relatively less time within the climate chamber, especially the 0, 1, 5, and 10 cycle connections, were more prone to Mode III_m yields at failure, but this was not always the outcome. Figure 4.35 is a picture of a connection that was exposed to the longest treatment regime (40 cycles) and exhibited a Mode III_m yield. In this example, the side member material was able to sustain its integrity and resist the rotation of the nail shank.

Figure 4.35: Mode III_m failure of sample D7-11 (40 cycles).

Figure 4.36 shows a connection that failed by Mode III$_m$, but was not completely able to resist slight nail rotation and therefore displayed some nail head embedment in the side member face. As stated, there were many cases in which the side member was not able to counter the lateral rotation forces of the fastener during loading and therefore failed by Mode III$_s$ where the nail head was completely pulled through the sheathing, as shown in Figure 4.37.

Figure 4.36: Mode III$_m$ failure of sample D7-3 (40 cycles).

(a) (b)

Figure 4.37: Mode III$_s$ failure of samples D3-15 (5 cycles) and D7-14 (40 cycles).

4.4.6 – Density Analysis

Below, Figure 4.38 displays the mean density values of 'Mill D' type sheathing after 0 (control), 1, 5, 10, 15, 20, 25, and 30 cycles. Initially, the values increase slightly between the control and 1st cycle readings, then stabilize, and finally begin a downward trend as cycling progresses.

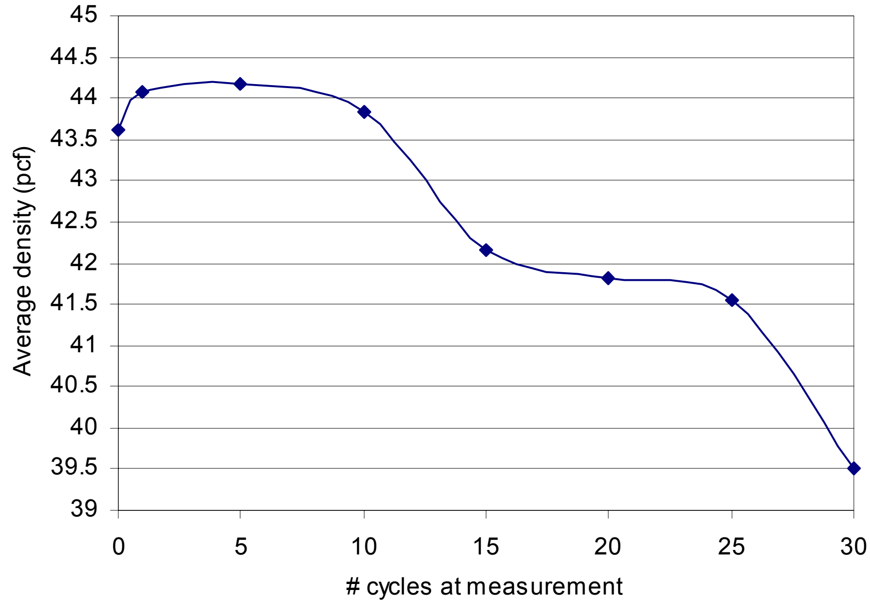


Figure 4.38: Average density of 'Mill D' sheathing.

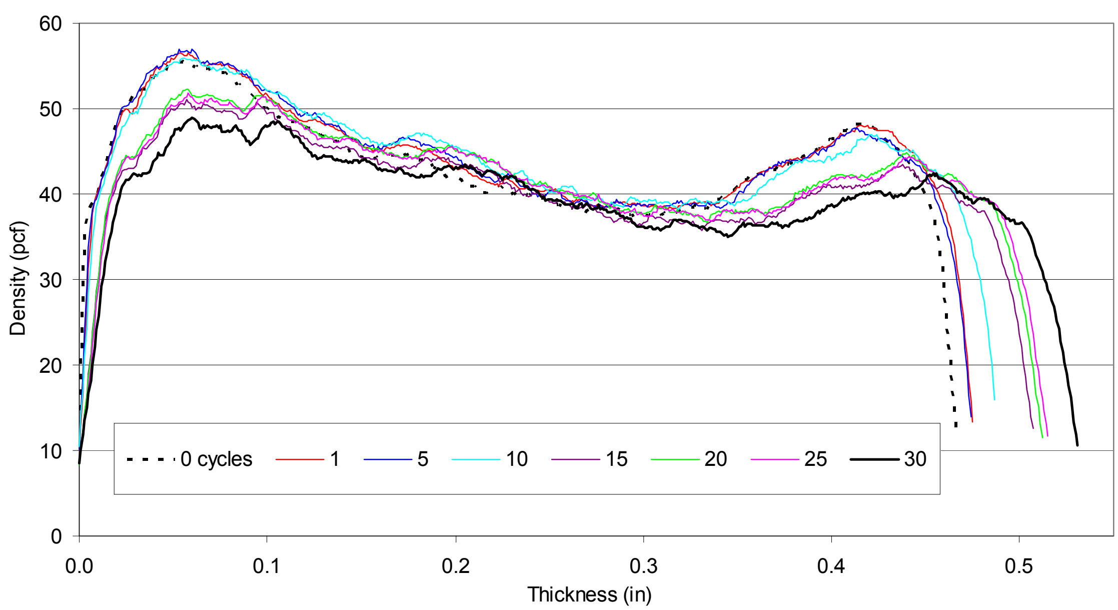


Figure 4.39: Overlay of 'Mill D' vertical-density profiles.

Figure 4.39 illustrates the VDP measurements, which indicate the density gradient across the thickness of 'Mill D' type sheathing during each cycling interval. The dense face layers clearly show evidence of more extreme de-densification as cycling increases when compared to the central core region. Unrecoverable thickness swell reaches 13.9% in relation to the original measurement. Table 4.50 shows the relative and cumulative density changes.

Table 4.50: Relative and cumulative changes in thickness of 'Mill D' sheathing.

		# cycles at measurement						
		1	**5**	**10**	**15**	**20**	**25**	**30**
Mill D	Vs. previous	2.0%	-0.1%	2.9%	3.9%	0.9%	0.6%	3.0%
	Vs. control	2.0%	1.9%	4.9%	9.0%	10.0%	10.6%	13.9%

4.4.7 – Yield Model Estimation

Table 4.51 summarizes the input parameters used in the yield model calculations. The dowel length used is less than the actual fastener measurement to exclude the tip (1.8 in. instead of 2.0 in.). This is specified in the AF&PA's *General dowel equations for calculating lateral connection values – Technical Report 12* (AF&PA 1999). The 5% offset loads observed in 'Mill D' connection tests were compared to the 5% offset yield calculated using the general dowel equations. Estimated values were developed using non-cycled materials. Comparisons were made with the results from each treatment group (Table 4.52). A Mode III_s yield was specified by the equations with a load of 96 lbs. at the 5% offset. This differs from the reported mode at failure (Mode III_m) because the general dowel equations only estimate the mode at yield. The predicted vs. observed ratios (P/O) indicate similarities with each treatment group. Prior examination of 'Mill D' connection results do not present a clear trend and are primarily unchanged over the entire cycling period.

Table 4.51: Yield model input parameters for 'Mill D' connection components.

Main Member			Side Member			Fastener		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.32	2405	12.0%	0.48	3992	23.9%	0.113	41.3	4.1%

Table 4.52: Comparisons of observed vs. predicted 5% offset loads for 'Mill D' connections.

		Observed mean (lb)	Observed COV	Predicted (lb)	Predicted yield	P/O
conditioning cycles	0 (control)	110	19.3%	96	Mode III_s	87%
	1	93	21.4%			103%
	5	86	25.4%			112%
	10	110	19.2%			87%
	15	83	24.7%			116%
	25	100	19.0%			96%
	40	92	10.5%			104%

4.5 – 'Mill E' Connections

'Mill E' connections were made from stud grade SF main members and 19/32 in. OSB side members. The fasteners used were uncoated 8d wire nails. Table 4.53 provides the summary statistics for performance values observed and collected during all cycle periods. This connection configuration was capable of sustaining maximum loads between 300 and 350 lbs. at about 1.0 to 1.2 in. of slip. High variability in elastic stiffness performance is evident by the large COV percentages. Figure 4.40 depicts the load/slip plot of sample E3-8, which is similar in shape and magnitude to nearly all 'Mill E' connections.

Table 4.53: Observed metrics and predictions of 'Mill E' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (E1)	mean	11828	154	322	86.7%	13.3%
	COV	41.5%	18.8%	19.0%		
1 cycle (E2)	mean	10252	157	362	93.3%	6.7%
	COV	36.6%	17.3%	30.3%		
5 cycles (E3)	mean	7847	146	339	93.3%	6.7%
	COV	41.1%	28.4%	17.2%		
10 cycles (E4)	mean	6117	131	299	100.0%	0.0%
	COV	32.2%	16.6%	23.0%		
15 cycles (E5)	mean	6921	134	339	93.3%	6.7%
	COV	38.8%	15.0%	24.8%		
25 cycles (E6)	mean	9154	146	299	100.0%	0.0%
	COV	44.1%	19.5%	24.5%		
40 cycles (E7)	mean	10431	127	334	80.0%	20.0%
	COV	31.7%	17.4%	24.3%		
Yield Model Prediction	**Lateral Resistance (lb)**		**149**			
	Yield Mode		III_s			

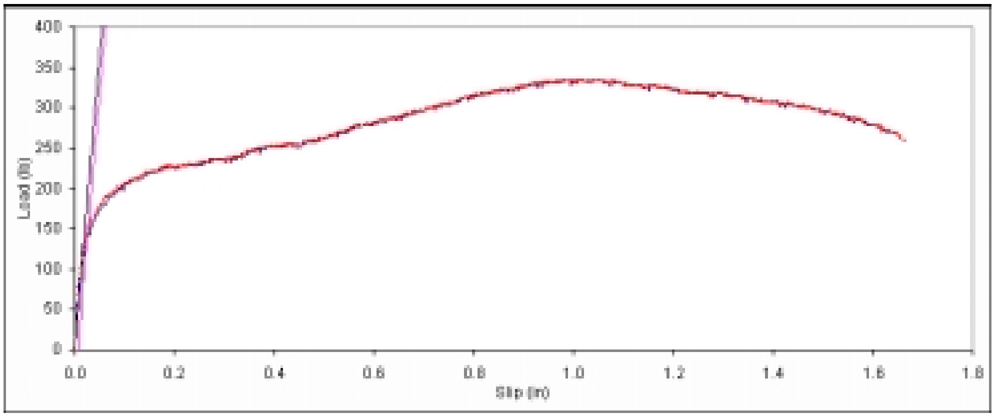


Figure 4.40: Typical load/slip plot of a 'Mill E' connection (sample E3-8).

4.5.1 – Moisture Contents and Specific Gravities

In the case of 'Mill E' connections, the main member components were found to have MC values between 10.7% and 11.7% with an overall mean value of 11.22% and a 3.2% COV. MC of the side member materials were slightly more variable with a COV of 4.8% and values ranging between about 8.0% and 9.2% MC. SG values of main members were representative of the species used for manufacture at 0.35 and 2.9% COV. Side member specific gravities had a mean value of 0.67 and a 4.3% COV (Table 4.54).

Table 4.54: Moisture content (at testing) and specific gravity values of 'Mill E' connection components.

		Main Member				Side Member			
		% moisture content		specific gravity		% moisture content		specific gravity	
		mean	COV	mean	COV	mean	COV	mean	COV
conditioning cycles	0	12 *	---	0.35	8.7%	12 *	---	0.70	8.8%
	1	11.2	3.8%	0.35	8.8%	8.0	3.7%	0.70	8.8%
	5	11.2	5.6%	0.37	3.9%	8.4	5.3%	0.63	4.2%
	10	11.5	10.9%	0.34	7.0%	8.9	1.7%	0.63	6.6%
	15	11.7	4.2%	0.34	4.4%	9.2	4.6%	0.68	8.6%
	25	10.8	5.4%	0.35	7.0%	8.7	2.1%	0.69	3.7%
	40	11.0	4.5%	0.36	4.8%	8.7	2.5%	0.67	5.3%
Overall		**11.2**	**3.2%**	**0.35**	**2.9%**	**8.6**	**4.8%**	**0.67**	**4.3%**

** Zero cycle connections (controls) assumed 12% MC.*

4.5.2 – Elastic Stiffness Performance

Figure 4.41 illustrates a decrease in the elastic stiffnesses of 'Mill E' connections until after the 10th cycle when the values rebound to nearly the equivalent magnitude of the original test results. A p-value of 0.0001 confirms the significant differences. Furthermore, the subsequent t-test reports the important differences are between the control and 5th cycle values and between the 5th and 40th cycle results (Table 4.55). The LSD procedure clusters test results in response to the u-shaped trend seen in the plot. The initial values (0 cycles) are paired with the last results (40 cycles), the second (1 cycle) with the second to last (25 cycles), and so forth (Table 4.56). The elastic stiffness values received from the 10th cycle tests are the lowest while the control values are the highest. As with all elastic stiffness values observed in each connection type, considerable variability limits the statistical inferences allowed.

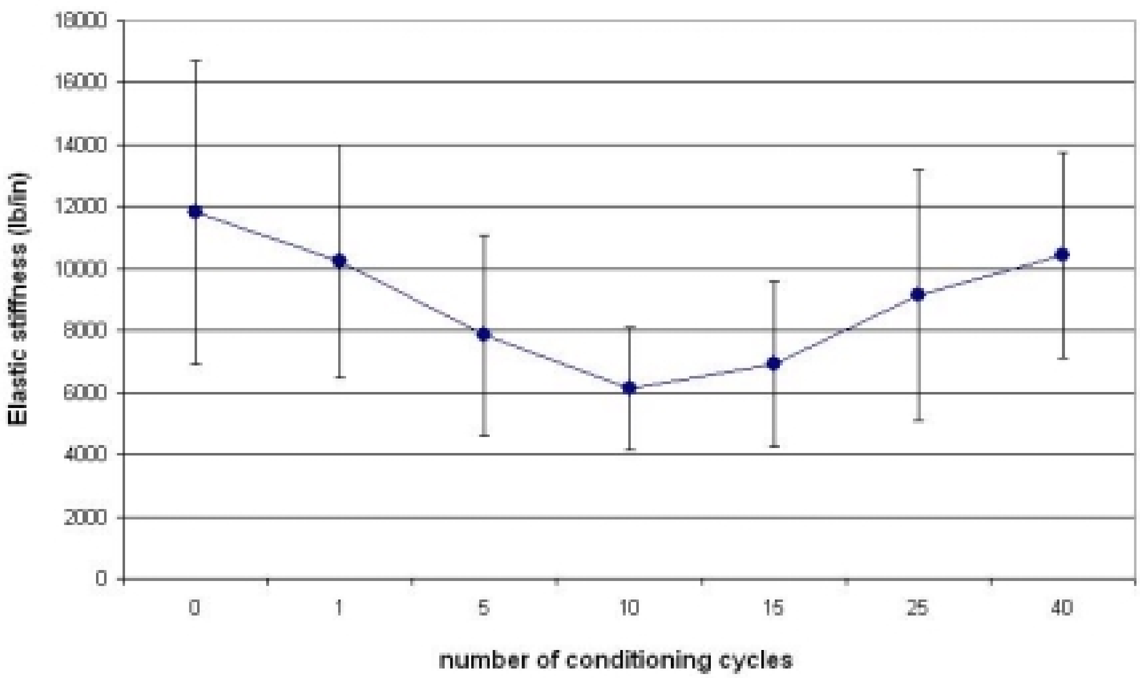


Figure 4.41: Observed elastic stiffness values of 'Mill E' connections.

Table 4.55: Two tailed t-test results of 'Mill E' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.988	2.056	NO
1	5	1.883	2.052	NO
0	5	2.624	2.064	YES
5	10	1.773	2.069	NO
5	15	0.854	2.052	NO
5	25	0.979	2.052	NO
5	40	2.167	2.048	YES
25	40	0.948	2.052	NO

Table 4.56: Fisher's LSD results of 'Mill E' elastic stiffness values (95% CI).

Treatment (cycles)	0	40	1	25	5	15	10
mean:	11828	10431	10252	9154	7847	6921	6117
grouping:	A	A	A				
		B	B	B			
			C	C	C		
				D	D	D	
					E	E	E

4.5.3 – 5% Offset Yield Performance

Below, Figure 4.42 illustrates the performance of the 'Mill E' connections in terms of the observed 5% offset yield load. Generally, as cycling continued the performance declined, slightly. A p-value of 0.0269 signifies that the differences among the results are significant, but just barely since an alpha value of 0.05 is used. T-test procedures found no significant differences between treatment groups with an exception for the control and 10th cycle results where a statistical difference is noted (Table 4.57). The Fisher's LSD test shows three overlapping groupings as shown in Table 4.58. Values for the 5th and 25th cycle are actually equal and are included in all three sets.

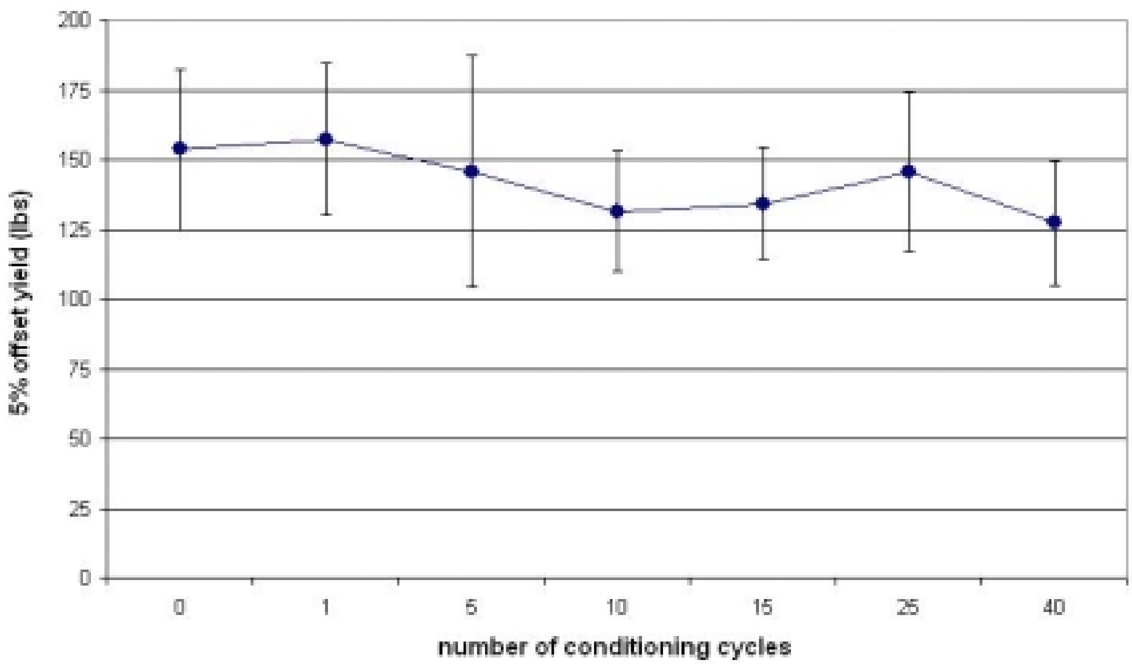


Figure 4.42: Observed 5% offset loads of 'Mill E' connections.

Table 4.57: Two tailed t-test results of 'Mill E' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	0.355	2.048	NO
1	5	0.897	2.064	NO
0	5	0.602	2.060	NO
0	10	2.378	2.056	YES
5	10	1.187	2.080	NO
10	15	0.367	2.048	NO
10	25	1.526	2.056	NO
10	40	0.506	2.048	NO

Table 4.58: Fisher's LSD results of 'Mill E' 5% offset yield values (95% CI).

Treatment (cycles)	1	0	5	25	15	10	40
mean:	157	154	146	146	134	131	127
grouping:	A	A	A	A			
		B	B	B	B		
			C	C	C	C	C

4.5.4 – Maximum Yield Performance

As shown in Figure 4.43, the maximum load performance of 'Mill E' connections ranged between 300 and 360 lbs. with no major effect as cycling progressed. Statistical differences among the mean values are not present, as indicated by a large p-value of 0.2711. Furthermore, the t-test performed does not show any significant differences among the individual cycle results (Table 4.59). Nevertheless, the LSD procedure specifies two groupings, which overlie each other heavily with four cycles common to both sets (Table 4.60).

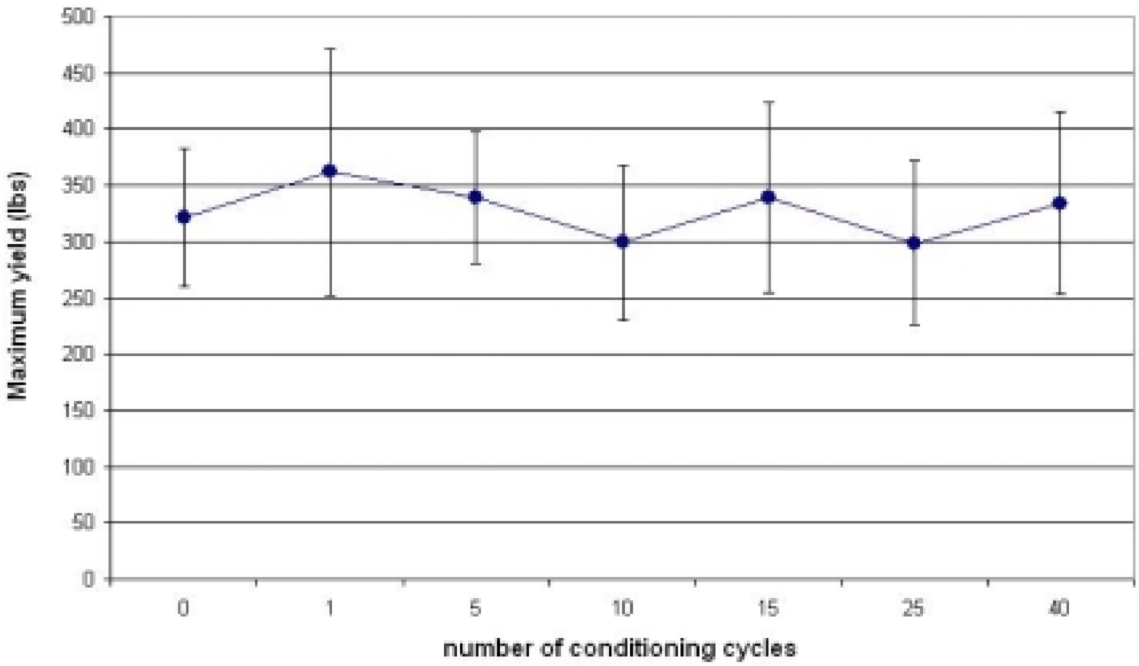


Figure 4.43: Observed maximum loads of 'Mill E' connections.

Table 4.59: Two tailed t-test results of 'Mill E' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	1.235	2.074	NO
1	5	0.705	2.080	NO
0	5	0.799	2.048	NO
0	10	0.946	2.048	NO
0	15	0.657	2.056	NO
0	25	0.929	2.052	NO
0	40	0.479	2.056	NO

Table 4.60: Fisher's LSD results of 'Mill E' maximum yield values (95% CI).

Treatment (cycles)	1	15	5	40	0	10	25
mean:	362	339	339	334	322	299	299
grouping:	A	A	A	A	A		
		B	B	B	B	B	B

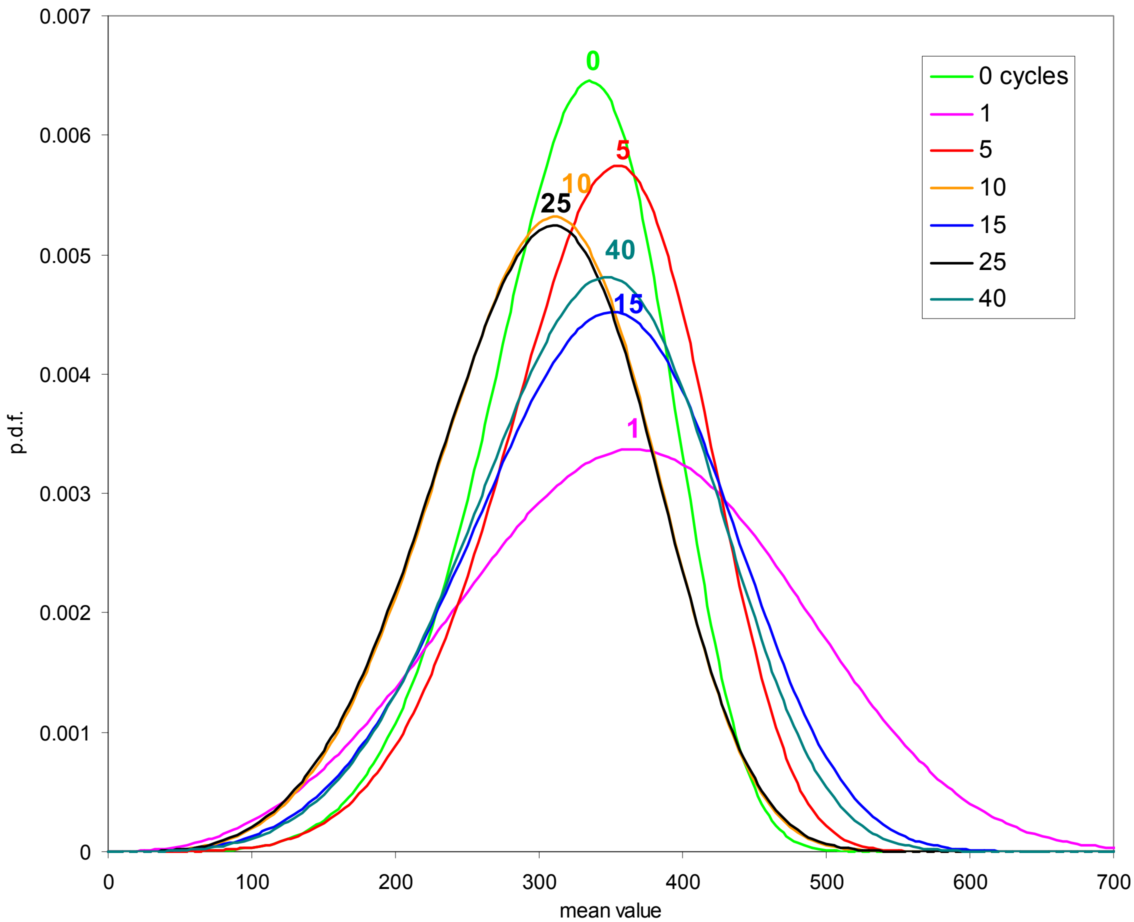


Figure 4.44: Probability density distributions of maximum yield loads for 'Mill E' connections (0-40 cycles).

Table 4.61: Weibull distribution parameters.

cycle:	0	1	5	10	15	25	40
scale, ***a***	346.44	402.78	367.16	327.84	371.73	327.37	365.61
shape, ***b***	5.99	3.53	5.64	4.62	4.44	4.54	4.66

The probability density distribution of the maximum loads observed from 'Mill E' connections is depicted in Figure 4.44. In conjunction with the Weibull PDF, both scale and shape parameters were used to create the mound shapes corresponding to the test results from each cycle (Table 4.61). As discussed previously, the mean values are similar and this is shown in the plot of overlaid distribution curves. Differences exist in the height of the curves, which is determined by a change in central tendency of the data, and therefore, the spread or variability. The control dataset (0 cycles) is less disperse and stands higher above the other curves. The 5^{th}, 10^{th}, 15^{th}, 25^{th}, and 40^{th} cycle distributions of maximum load results are relatively alike in contrast to the 1^{st} cycle curve, which is shorter and thus, describes more variability among the values observed.

4.5.5 – Failure Yield

The 'Mill E' connections most often exhibited Mode III_m yields at failure in contrast to Mode III_s yields. However, as cyclic humidity conditioning increased the percentage of Mode III_s yield observed at failure increased slightly with an 80%/20% split in the 40^{th} cycle results (Table 4.62). Figure 4.45 is an example of the most common yield at failure for 'Mill E' connections, Mode III_m.

Table 4.62: Yield modes observed at failure for 'Mill E' connections.

		0	1	5	10	15	25	40
Yield Mode	III_m	86.7%	93.3%	93.3%	100.0%	93.3%	100.0%	80.0%
	III_s	13.3%	6.7%	6.7%	0.0%	6.7%	0.0%	20.0%

Figure 4.45: Mode III_m failure of sample E5-7 (15 cycles).

Although uncommon, especially in the control to 25th cycle tests, some Mode III_s yields were observed at failure. Examples of connections samples that showed this behavior are shown in Figure 4.46.

(a) *(b)*

Figure 4.46: Mode III_s failure of samples E3-11 (5 cycles) and E7-11 (40 cycles).

4.5.6 – Density Analysis

Figure 4.47 illustrates the mean density values of 'Mill E' type sheathing materials after cycling. Initially decreasing, the values increase slightly between the 1st and 5th readings, but return to a decreasing trend as cycling progresses toward 30 cycles.

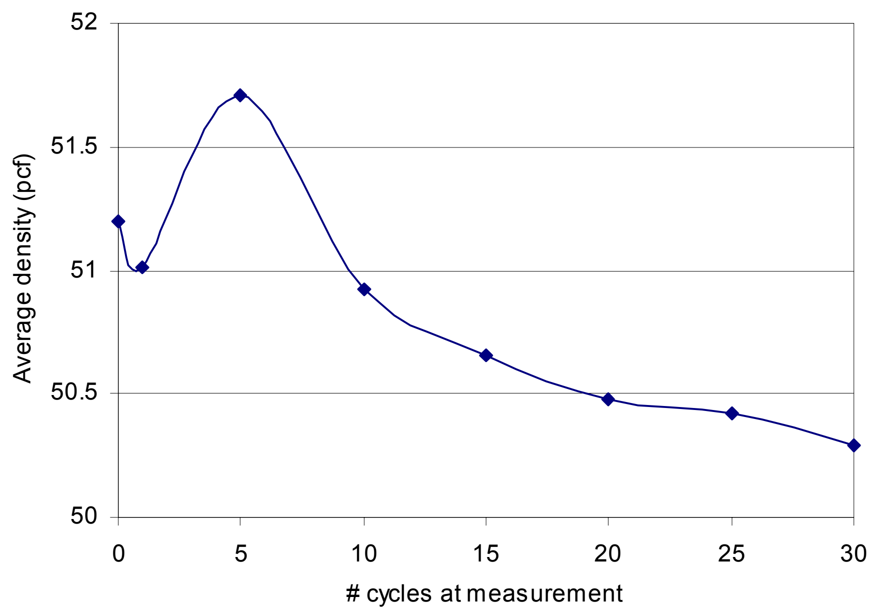


Figure 4.47: Average density of 'Mill E' sheathing.

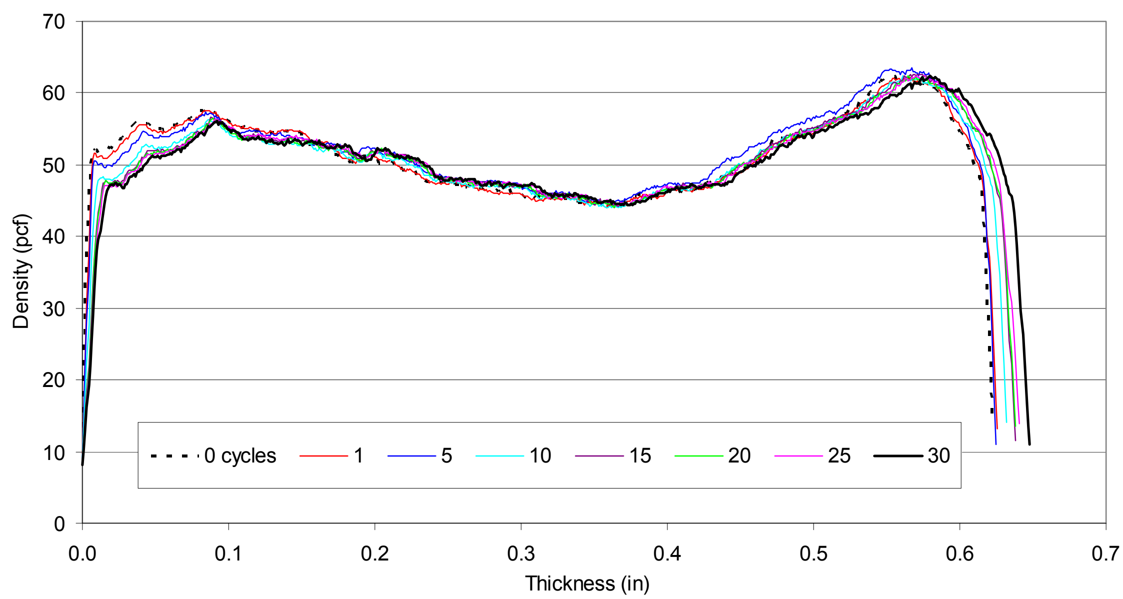


Figure 4.48: Overlay of 'Mill E' vertical-density profiles.

Figure 4.48 shows the VDP measurements collected after each specified cycle. The dense face layers show evidence of slightly more de-densification in comparison to the core region. Unrecoverable thickness swell is minimal and reaches 4.0%. Table 4.63 provides calculations of the increases in thickness as cycling progressed.

Table 4.63: Relative and cumulative changes in thickness of 'Mill E' sheathing.

		# cycles at measurement						
		1	**5**	**10**	**15**	**20**	**25**	**30**
Mill E	Vs. previous	0.5%	-0.2%	1.3%	0.9%	0.1%	0.6%	0.9%
	Vs. control	0.5%	0.2%	1.5%	2.4%	2.5%	3.1%	4.0%

4.5.7 – Yield Model Estimation

Table 4.64 summarizes the data for each factor needed for the yield model calculations. Note that the dowel bearing length used in the calculations is less than the actual fastener length to rule out the effect of the nail's tip (2.25 in. instead of 2.5 in.). The 5% offset loads observed in 'Mill E' connection tests were compared to the 5% offset yield calculated using the general dowel equations. Estimated values were developed using non-cycled materials (only conditioned to 12% MC) and therefore, are most analogous to the 0 cycle (control) connections. As shown in Table 4.65, comparisons were made with the results from each treatment group. A Mode III_s yield and load of 149 lbs. was calculated by the equations at the 5% offset. The mode is different from what was reported at failure (Mode III_m) as the general dowel equations only estimate the mode at yield. The predicted vs. observed ratios (P/O) indicate similarities with the control group, but as measured 5% offset values decline with increased cycling, more deviation from the estimate is apparent. This concurs with previous findings of slight decreases in 5% offset performance as cycling increased.

Table 4.64: Yield model input parameters for 'Mill E' connection components.

Main Member			Side Member			Fastener		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.65	2405	12.2%	0.60	5112	20.0%	0.131	70.9	4.0%

Table 4.65: Comparisons of observed vs. predicted 5% offset loads for 'Mill E' connections.

		Observed		Predicted		P/O
		mean (lb)	COV	(lb)	yield	
conditioning cycles	0 (control)	154	18.8%	149	Mode III_s	97%
	1	157	17.3%			95%
	5	146	28.4%			102%
	10	131	16.6%			114%
	15	134	15.0%			111%
	25	146	19.5%			102%
	40	127	17.4%			117%

4.6 – 'Mill F' Connections

Each 'Mill F' connection was fabricated from a SF stud grade main member and 15/32 in. plywood side member. A 6d uncoated wire nail was used as the fastener. Table 4.66 provides summary statistics for observed performance parameters during all cycle periods. This connection configuration afforded a maximum yield near 275 lbs. at about 1.0 in. of slip. Figure 4.49 depicts the load/slip plot of sample A3-9, a curve similar to nearly all 'Mill A' connections.

Table 4.66: Observed metrics and predictions of 'Mill F' connections.

		Elastic Stiffness (lb/in)	5% Offset Load (lb)	Max. Load (lb)	Yield Mode @ Failure (% Observed)	
					III_m	III_s
control (F1)	mean	11183	116	262	100.0%	0.0%
	COV	53.0%	18.4%	18.8%		
1 cycle (F2)	mean	7177	94	228	100.0%	0.0%
	COV	61.6%	32.0%	27.6%		
5 cycles (F3)	mean	6308	79	199	100.0%	0.0%
	COV	50.6%	12.3%	20.1%		
10 cycles (F4)	mean	5846	84	231	93.3%	6.7%
	COV	44.7%	15.4%	21.9%		
15 cycles (F5)	mean	3916	90	296	73.3%	26.7%
	COV	29.4%	20.5%	17.7%		
25 cycles (F6)	mean	3832	93	313	66.7%	33.3%
	COV	25.1%	13.7%	12.7%		
40 cycles (F7)	mean	3513	90	315	66.7%	33.3%
	COV	47.9%	9.9%	13.0%		
Yield Model Prediction	**Lateral Resistance (lb)**		**106**			
	Yield Mode		$\mathbf{III_s}$			

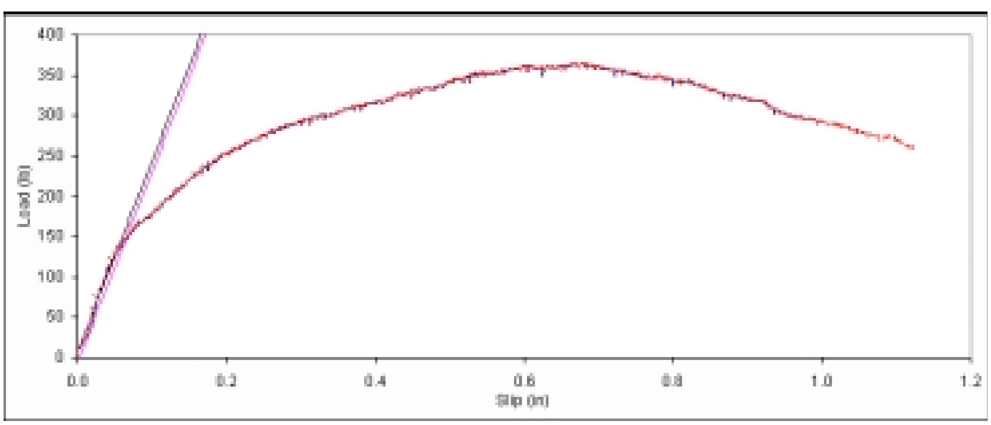


Figure 4.49: Typical load/slip plot of a 'Mill F' connection (sample F5-13).

4.6.1 – Moisture Contents and Specific Gravities

As seen below in Table 4.67, main member mean MC values were 11.60% with a 4.7% overall COV. Side members had mean MC values of 9.63% with a 9.2% COV. Specific gravity values were 0.34 for the main member materials and 0.58 for the side member materials with 5.9% and 5.8% COV values, respectively.

Table 4.67: Moisture content (at testing) and specific gravity values of 'Mill F' connection components.

		Main Member				Side Member			
		% moisture content		specific gravity		% moisture content		specific gravity	
		mean	COV	mean	COV	mean	COV	mean	COV
conditioning cycles	0	12 *	---	0.35	8.3%	12 *	---	0.58	3.6%
	1	11.2	5.2%	0.35	8.7%	8.5	6.0%	0.55	3.7%
	5	11.1	7.1%	0.30	4.7%	9.4	6.1%	0.65	4.8%
	10	12.2	2.1%	0.34	5.1%	10.4	7.2%	0.58	4.7%
	15	12.3	5.9%	0.35	7.2%	10.9	5.6%	0.55	5.8%
	25	11.7	1.7%	0.34	4.2%	9.34	1.6%	0.57	6.2%
	40	11.1	3.3%	0.35	5.2%	9.34	2.9%	0.58	4.9%
Overall		**11.6**	**4.7%**	**0.34**	**5.9%**	**9.64**	**9.2%**	**0.58**	**5.8%**

** Zero cycle connections (controls) assumed 12% MC.*

4.6.2 – Elastic Stiffness Performance

Elastic stiffness values observed in 'Mill F' connections showed a steady decline as cyclic moisture conditioning continued (Figure 4.50). A p-value of <0.0001 proves significant contrasts exist among the results and a t-test identifies the differences as being between the control and 1st cycle tests and between the 1st and 15th cycles (Table 4.68). Fisher's LSD follows this decision by grouping the mean values into three classes. The control reading, although highly variable, is set apart from the other values, which occupy two overlapping groups (Table 4.69). The ordered elastic stiffness values do follow the chronological sequence with the control results being the largest and the 40th cycle results being the smallest.

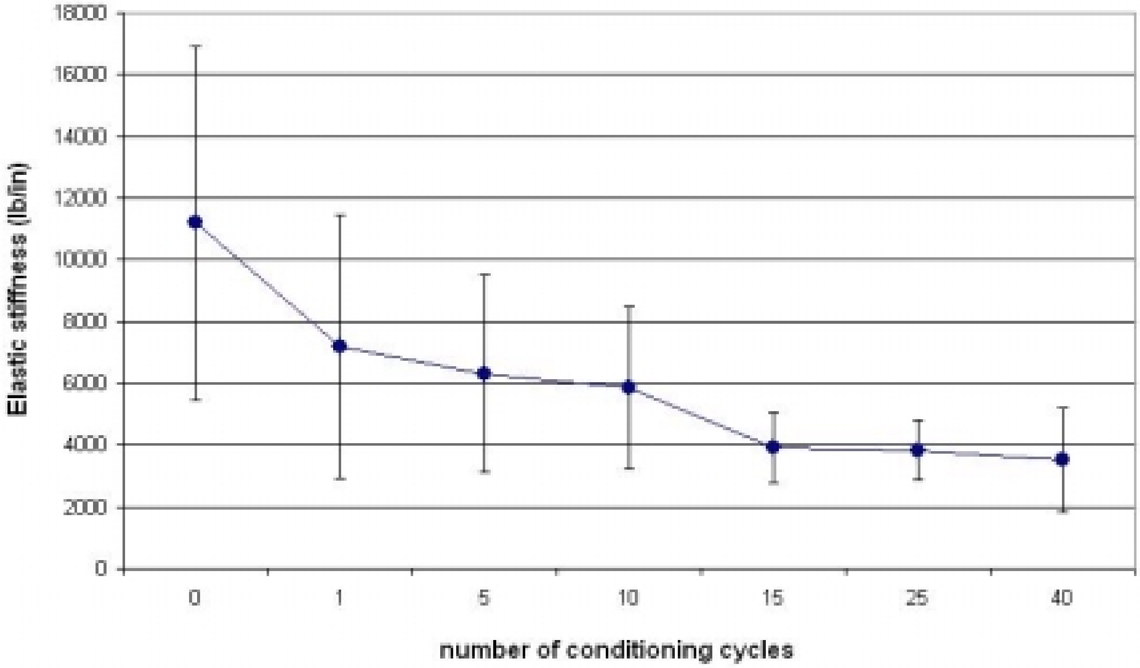


Figure 4.50: Observed elastic stiffness values of 'Mill F' connections.

Table 4.68: Two tailed t-test results of 'Mill F' elastic stiffness values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	2.083	2.056	YES
1	5	0.632	2.056	NO
1	10	1.031	2.069	NO
1	15	2.861	2.120	YES
15	25	0.217	2.052	NO
15	40	0.766	2.060	NO

Table 4.69: Fisher's LSD results of 'Mill F' elastic stiffness values (95% CI).

Treatment (cycles)	0	1	5	10	15	25	40
mean:	11183	7177	6308	5846	3916	3832	3513
grouping:	A						
		B	B	B			
				C	C	C	C

4.6.3 – 5% Offset Yield Performance

The performance of 'Mill F' connections during each testing stage is presented in Figure 4.51. A decreasing effect is observed from the control to 5th cycle and then the results appear to stabilize. While a p-value of <0.0001 is produced by an ANOVA, the two-tailed t-test only resolves one significant difference between the control and 1st cycle results. Following the 1st cycle test observations, the data is determined not to be dissimilar (Table 4.70). Shown in Table 4.71, Fisher's LSD procedure placed the control reading in its own group, while subsequent results are located in two overlapping groupings.

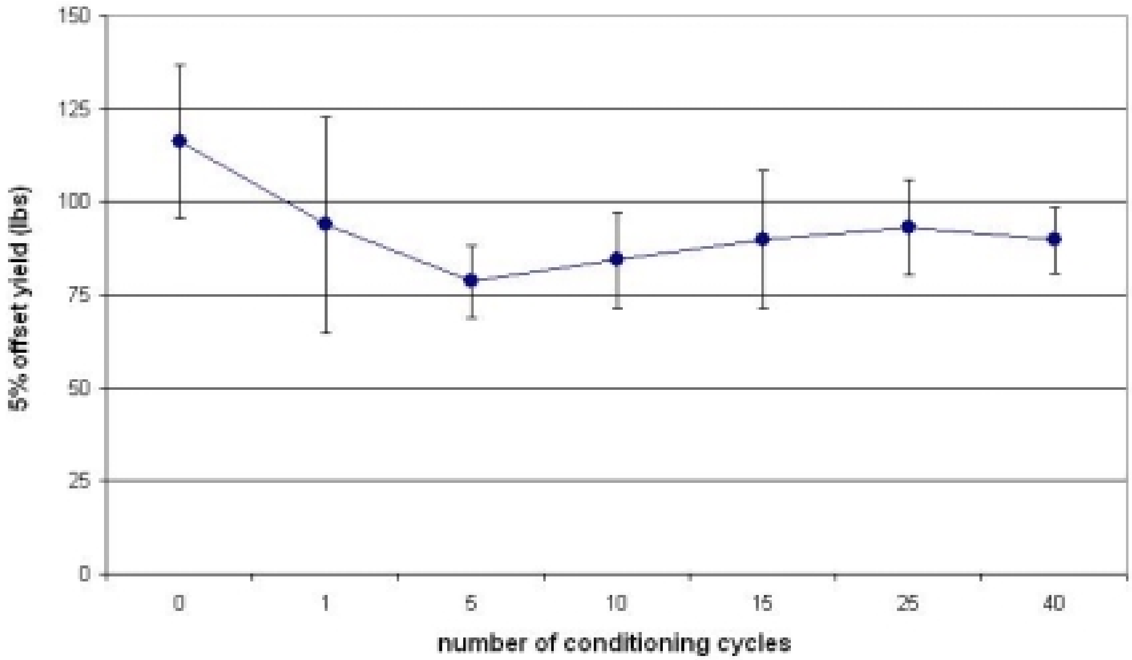


Figure 4.51: Observed 5% offset loads of 'Mill F' connections.

Table 4.70: Two tailed t-test results of 'Mill F' 5% offset yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	2.454	2.060	YES
1	5	1.920	2.110	NO
1	10	1.147	2.093	NO
1	15	0.441	2.064	NO
1	25	0.086	2.093	NO
1	40	0.517	2.110	NO

Table 4.71: Fisher's LSD results of 'Mill F' 5% offset yield values (95% CI).

Treatment (cycles)	0	1	25	40	15	10	5
mean:	116	94	93	90	90	84	79
grouping:	A						
		B	B	B	B	B	
				C	C	C	C

4.6.4 – Maximum Yield Performance

The maximum yield performance of 'Mill F' connections ranged between approximately 200 to 315 lbs., in terms of average test values (Figure 4.52). A p-value of <0.0001 is indicated by an ANOVA and a t-test, shown in Table 4.72, specifies significant differences between the 1st and 5th cycles, 5th and 15th, and the 10th and 15th test results. Groupings determined by Fisher's LSD procedure are described in Table 4.73. Four groups are shown and the order is somewhat analogous to the chronological order of connection tests.

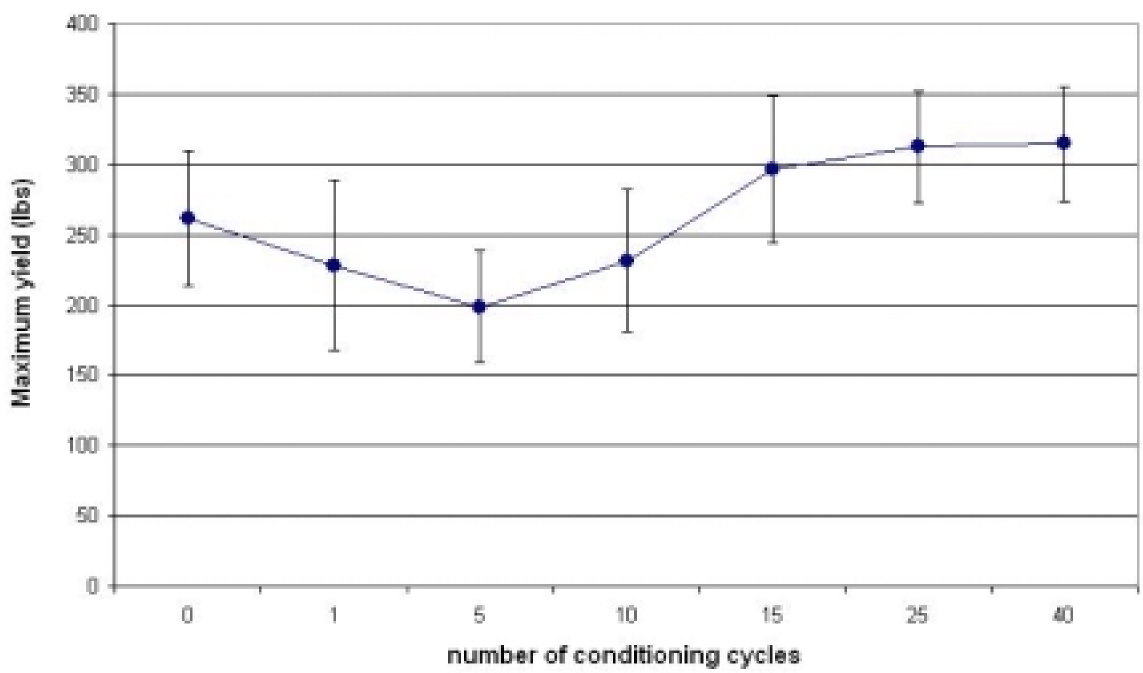


Figure 4.52: Observed maximum loads of 'Mill F' connections.

Table 4.72: Two tailed t-test results of 'Mill F' maximum yield values (95% CI).

Primary Cycle	Vs. Cycle	T-Statistic	T-Critical	Sig. Diff.?
0	1	1.692	2.056	NO
1	5	3.921	2.052	YES
5	10	1.955	2.052	NO
5	15	5.728	2.056	YES
10	15	3.444	2.048	YES
15	25	0.972	2.056	NO
15	40	1.072	2.056	NO

Table 4.73: Fisher's LSD results of 'Mill F' maximum yield values (95% CI).

Treatment (cycles)	40	25	15	0	10	1	5
mean:	315	313	296	262	231	228	199
grouping:	A	A	A				
			B	B			
				C	C	C	
					D	D	D

The maximum load data for all 'Mill F' connections are described by probability density distributions in Figure 4.53. The associated scale and shape factors are provided in Table 4.74. The shorter, more spread mounds illustrate variability within the datasets. In contrast, the 5th and 25th cycle values are less variable and exhibit more central tendency. Overall, the distributions are shifted in the positive x-direction as cyclic relative humidity exposure increased.

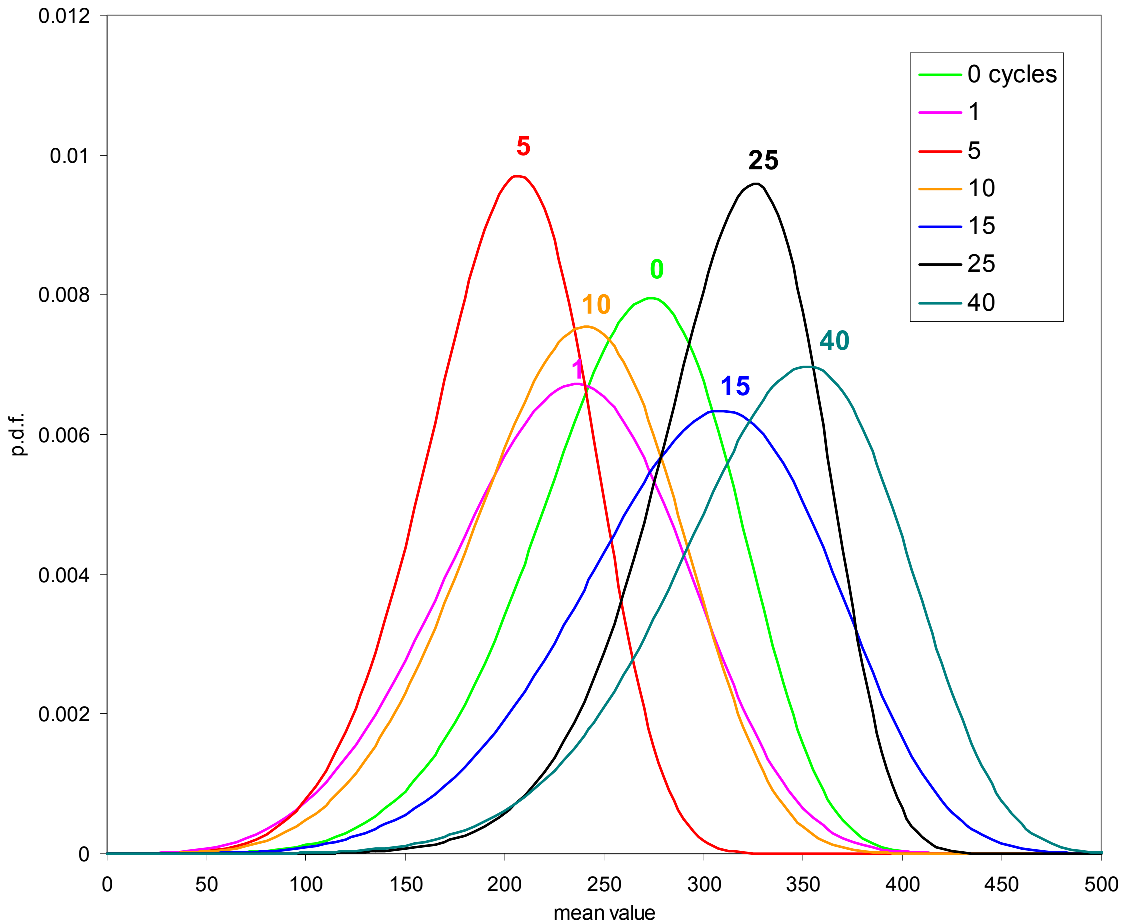


Figure 4.53: Probability density distributions of maximum yield loads for 'Mill F' connections (0-40 cycles).

Table 4.74: Weibull distribution parameters.

cycle:	0	1	5	10	15	25	40
scale, ***a***	281.45	250.03	214.89	251.54	321.28	330.27	360.51
shape, ***b***	6.00	4.44	5.57	5.05	5.44	8.54	6.76

4.6.5 – Failure Yield

The yield modes observed at failure for the 'Mill F' connection were mostly contained to Mode III_m in the less cycled samples, but as the cycling periods increased the amount of connections exhibiting Mode III_s yields at failure also increased. This is indicated in Table 4.75, below. The side member material in this type of connection configuration was 15/32 in. plywood and proved to be resistant to deterioration by the cyclic humidity conditioning. This sustained integrity resulted in the mostly Mode III_m yields at failure. Figure 4.54 is an example of the post-test conditions typically observed with the 'Mill F' connections at failure. In the 10^{th} to 40^{th} cycle tests there were more Mode III_s yields observed as weakening of outer plies progressed enough to permit nail pull through, as shown in Figure 4.55.

Table 4.75: Yield modes observed at failure for 'Mill F' connections.

		0	1	5	10	15	25	40
Yield Mode	III_m	100.0%	100.0%	100.0%	93.3%	73.3%	66.7%	66.7%
	III_s	0.0%	0.0%	0.0%	6.7%	26.7%	33.3%	33.3%

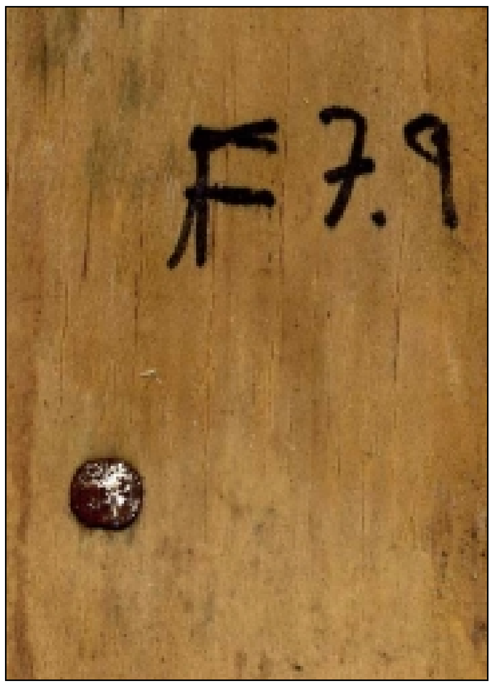
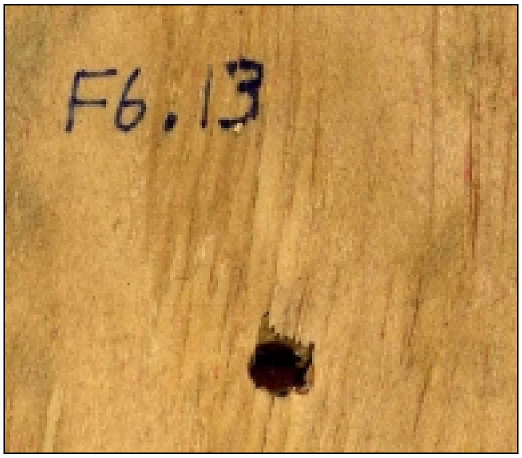


Figure 4.54: Mode III_m failure of sample F7-9 (40 cycles).



(a)

(b)

Figure 4.55: Mode III_s failure of samples F6-13 (25 cycles) and F7-5 (40 cycles).

4.6.6 – Density Analysis

Below, Figure 4.56 displays the mean density values of 'Mill F' type sheathing after 0 (control), 1, 5, 10, 15, 20, 25, and 30 cycles. Initially increasing, the values begin to decrease following the 1^{st} cycle readings.

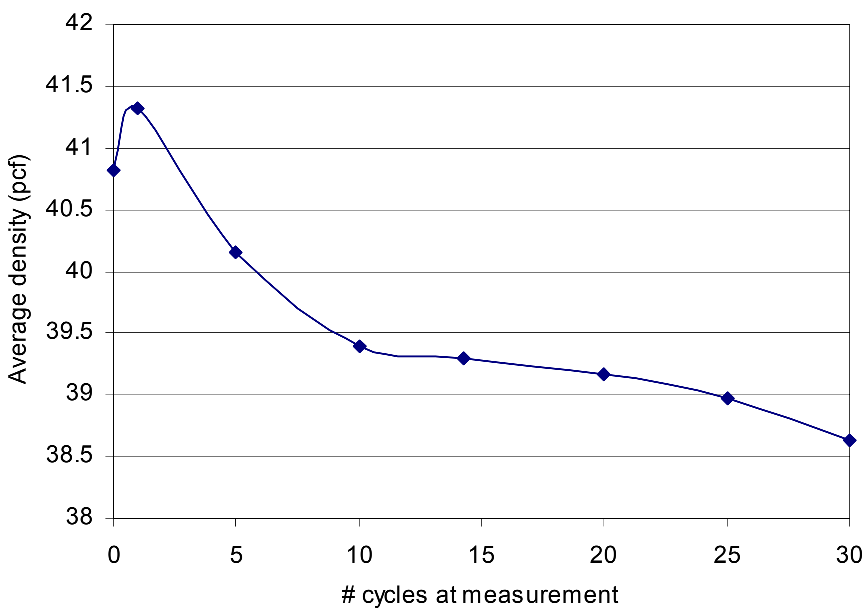


Figure 4.56: Average density of 'Mill F' sheathing.

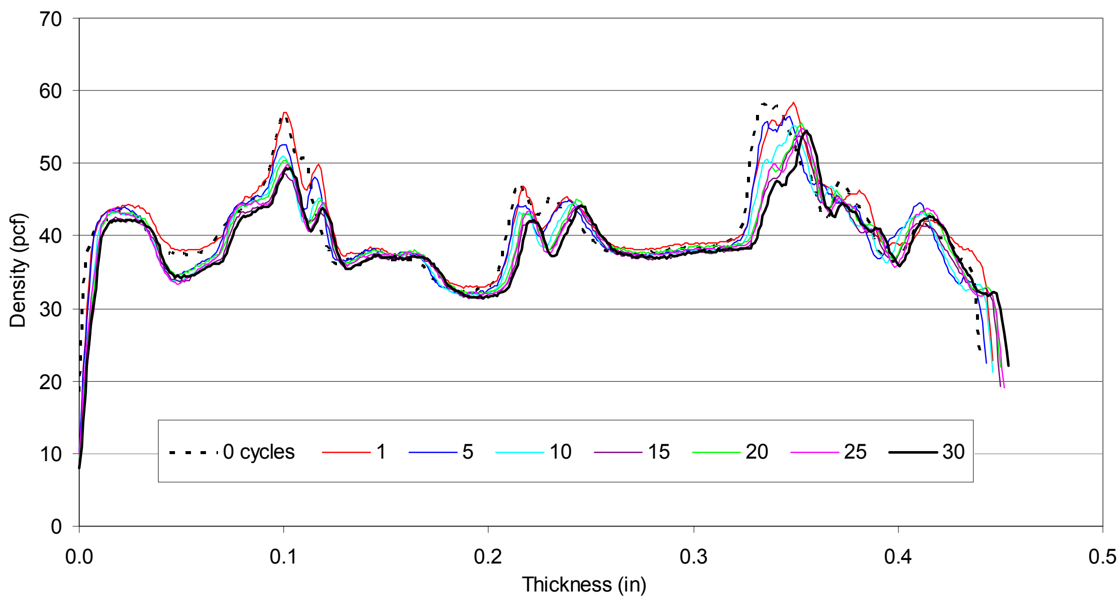


Figure 4.57: Overlay of 'Mill F' vertical-density profiles.

Figure 4.57 illustrates how density changed across the thickness of 'Mill F' type sheathing samples during cycling. Although not normally used with plywood veneer products, VDP was used here as a method of observing any changes in density across the thickness during cycling. Average results are likely unuseful as they are influenced by the gluelines, which are very dense as evidenced by the three major peaks seen in Figure 4.57. Unrecoverable thickness swell accounted for a 3.7% thickness increase. Relative and cumulative density changes between cycles are provided in Table 4.76.

Table 4.76: Relative and cumulative changes in thickness of 'Mill F' sheathing.

		# cycles at measurement						
		1	**5**	**10**	**15**	**20**	**25**	**30**
Mill F	Vs. previous	1.2%	-0.6%	1.1%	0.9%	0.0%	0.3%	0.7%
	Vs. control	1.2%	0.7%	1.8%	2.7%	2.7%	3.1%	3.7%

4.6.7 – Yield Model Estimation

Table 4.77 summarizes the data for each parameter required in the yield model calculations. Note that the dowel length used in the calculations is less than the actual fastener measurement to exclude the diamond pointed tip (1.8 in. instead of 2.0 in.) as specified in the AF&PA's *General dowel equations for calculating lateral connection values – Technical Report 12* (AF&PA 1999). The 5% offset loads observed in 'Mill F' connection tests were compared to the 5% offset yield calculated using the general dowel equations. Estimated values were developed using non-cycled materials (only conditioned to 12% MC). As shown in Table 4.78, comparisons were made with the results from each treatment group. This was done in order to examine the validity of the yield model in cycled, or aged, connections. A Mode III_s yield was specified by the equations with a load of 106 lbs. at the 5% offset limit. The mode is different from what was reported at failure (Mode III_m) as the general dowel equations only estimate the mode at yield. The predicted vs. observed ratios (P/O) indicate similarities with the control group and as experimental 5% offset results decline and then stabilize, the variation between predicted and observed values is more evident.

Table 4.77: Yield model input parameters for 'Mill F' connection components.

Main Member			**Side Member**			**Fastener**		
Bearing Length (in)	Dowel-bearing strength (psi)	COV	Bearing Length (in)	Dowel-bearing strength (psi)	COV	Dia. (in)	Dowel moment resistance (in-lbs)	COV
1.32	2405	12.03%	0.48	5286	6.94%	0.113	41.3	4.05%

Table 4.78: Comparisons of observed vs. predicted 5% offset loads for 'Mill F' connections.

		Observed		**Predicted**		**P/O**
		mean (lb)	COV	(lb)	yield	
conditioning cycles	0 (control)	116	18.4%	106	Mode III_s	91%
	1	94	32.0%			113%
	5	79	12.3%			134%
	10	84	15.4%			126%
	15	90	20.5%			118%
	25	93	13.7%			114%
	40	90	9.9%			118%

4.7 – Overall Discussion of Observations

4.7.1 – 'Mill A' Connections

The performance of this connection type was influenced by cyclic humidity exposure. Elastic stiffness exhibited a decreasing effect. The 5% offset yield loads were unchanged from the original control readings to the 25th cycle readings, but then dropped at the 40th. It is unclear if this trend continues past 40 cycles. The maximum loads observed from 'Mill A' connection tests increased as cycling also increased, but then declined sharply at the 40th cycle. Again, it is unclear how the connections would behave after more cycling. A PDF analysis of specific 'Mill A' type side member samples showed increasing variability within maximum load datasets as cycling continued. The number of Mode III_s yields seen upon failure increased as cycling increased. The average densities of the side member material changed from 45.8 to 43.6 lbs/ft^3 and a total thickness increase of 12.7% was realized, in comparison of the control to 30th cycle readings. Overall, it appears that as cycling time progressed the 'Mill A' type connections increasingly deteriorated and weakened. The loss of integrity of the component materials led to more instances of Mode III_s yields at failure as cycling continued. Yield model comparisons indicate similarities with the control group, but as experimental 5% offset values decline with increased cycling, variation increases. The unrecoverable thickness swell inherently increased the nail's bearing length within the sheathing and therefore, caused the maximum load values to increase. The general dowel equations state bearing length as being a critical parameter in determining connection strength.

4.7.2 – 'Mill B' Connections

In general, connection performance for this configuration was not adversely affected by cyclic humidity exposure. Elastic stiffness values calculated from test data indicated an overall unchanging effect. Significance tests were nullified because of the high variability within each elastic stiffness dataset. Furthermore, the 5% offset yield loads did not demonstrate a common trend. The maximum loads observed from 'Mill B' connection tests were found to increase somewhat as cycling increased, but again high variability was present in the test results. A PDF analysis of 'Mill B' side member samples specified a trend of lessening central tendency in datasets as cycling increased. This supports the general notion that the cyclic humidity exposure can, over time, degrade wood-based materials and thereby, increase the chances of observing a greater range of loads by changing the distribution of probable values. The number of Mode III_s yields at failure increased greatly as cycling increased. This is attributed to the de-densification of the face layers of the OSB material. The core layer exhibited minimal reduction in density. Overall, the average density declined by nearly 11% and unrecoverable thickness swell was the highest at 12.1% after 30 cycles. Yield model comparisons are similar with all treatment groups at the 5% offset limit state. Overall, it appears the 'Mill B' connections were not significantly weakened to a point where their performance was compromised, but instead a gain in capacity was seen because of thickness swell of the face layers. This expanding behavior is only an indication of the side member materials' potential and is likely to occur at a much slower rate if the sample was under constant load and less extreme environmental conditions (i.e., a typical in-service situation).

4.7.3 – 'Mill C' Connections

The performance of 'Mill C' type connections, which involved 7/16 in. OSB side members, was not significantly influenced by prolonged cyclic humidity conditioning. Both elastic stiffness and 5% offset load values demonstrated an overall unchanging trend. A tendency in the negative direction is slightly apparent, but large variability (>20% COV) limits possible inferences. Maximum loads seen in 'Mill C' tests showed an upward trend, which was likely the result of thickness swell. The VDP analysis indicated moderate decreases in face layer density while the core layer remained mostly constant. Average density diminished by 7.2% after 30 cycles to a minimum of 38.7 lbs/ft^3. Cumulative thickness swell achieved 7.2% in relation to the control measurements. Also, Mode III_s yields became more common upon failure as cycling progressed. Yield model comparisons show likenesses among all treatment groups. In general, the cyclic humidity exposure caused only small reductions in stiffness and yield of the 'Mill C' connections. The de-densification of the OSB face layers contributed to more side member failures, but also enhanced capacity performance as unrecoverable thickness swell ensued.

4.7.4 – 'Mill D' Connections

The performance of this connection type was greatly influenced by the treatment of cyclic humidity exposure. Elastic stiffness exhibited an immediate decreasing trend and then stabilized at a level 49% lower than the control, on average. The 5% offset results do not present a clear trend as the results repeatedly increased or decreased between each successive test result. The maximum loads observed from 'Mill D' tests increased steadily as cycling time also increased. The PDF analysis indicates a slight increase in the irregularity within maximum load values, especially after the 1st cycle. Furthermore, the number of Mode III_s yields seen at failure increased as cycling increased. The face layers were the major regions of de-densification. The average densities of the side member samples decreased by 9.4% from 43.6 to 39.5 lbs/ft^3. A 13.9% increase in thickness was measured as unrecoverable thickness swell accumulated over the 30 cycle period and contributed to increasing maximum loads, as explained previously. Yield model comparisons indicate similarities with each treatment group. As cycling time increased the 'Mill D' type connections lost stiffness and swelled significantly, losing necessary nail-holding abilities.

4.7.5 – 'Mill E' Connections

This connection type, involving a high-density 19/32 in. OSB side member, exhibited no significant change in any of the discussed performance parameters. Elastic stiffness values showed large variability and no clear trend. The 5% offset yield loads remained statistically the same during cycling. The maximum load values also remained identical throughout the cycling phase. PDF analysis of 'Mill E' side member samples produced inconclusive information. The proportion of Mode III_s yields observed at failure was very small in each cycle group tested. In addition, de-densification was nearly non-existent with a 1.8% total density loss after 30 cycles. Unrecoverable thickness swell only reached 4.0%. Yield model comparisons indicate similarities with the control group, but as measured 5% offset values decline with increased cycling, deviations from the estimate are apparent. Overall, 'Mill E' connections were not significantly influenced, either positively or negatively, by cyclic humidity conditioning and proved to be highly resistant to moisture infiltration. Elastic stiffness, 5% offset yield, and maximum yield remained unchanged as cycling periods increased. Furthermore, thickness swell was minute considering the drastic climate extremes.

4.7.6 – 'Mill F' Connections

The performance of 'Mill F' connections was not significantly influenced by prolonged cyclic humidity exposure. This configuration includes side members of four-ply 15/32 in. softwood plywood. Both elastic stiffness and 5% offset load values showed an initial decrease and then became constant throughout the last cycle periods. Maximum loads observed in 'Mill F' tests showed an initial decrease and then began demonstrating an increasing effect. The maximum load values stabilized between the 15th and 40th cycle tests. Also, Mode III_s yields became more common upon failure as cycling progressed. Average density diminished by 5.4% after 30 cycles to a minimum of 38.6 lbs/ft^3. Cumulative thickness swell achieved 3.7% in relation to the control measurements. This small increase in thickness was expected as plywood is made of solid wood veneers attached at several straight gluelines (three in this case). Without the consolidation/compaction process used in OSB production, the result is a panel product with less total wood material included and therefore, fewer interfaces and cavities for moisture infiltration. Yield model comparisons indicate similarities with the control group and as experimental 5% offset results decline and then stabilize, the variation between predicted and observed increases. In general, the cyclic humidity exposure caused minimal reductions in stiffness and yield of the 'Mill F' connections. The maximum loads increased slightly as unrecoverable thickness swell was small.