This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

Mechanical Property Data for Fiberboard

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Abstract

The 9975 shipping package incorporates a cane fiberboard overpack for thermal insulation and impact resistance. Mechanical properties (tensile and compressive behavior) have been measured on cane fiberboard and a similar wood-based product following short-term conditioning in several temperature/humidity environments. Both products show similar trends, and vary in behavior with material orientation, temperature and humidity. A memory effect is also seen in that original strength values are only partially recovered following exposure to a degrading environment and return to ambient conditions.

Background

The Savannah River Site (SRS) uses 9975 shipping packages to store plutonium materials in the K-Area Materials Storage (KAMS) facility [1]. The 9975 shipping packages perform several safety functions, including criticality, impact resistance, containment, and fire resistance to ensure the plutonium materials remain in a safe configuration during normal and accident conditions. Cane fiberboard is contained between the outer stainless steel drum and the inner lead shielding in the 9975 package. Safety functions specific to the cane fiberboard insulation include criticality control, impact resistance and fire resistance. Cane fiberboard is manufactured by Knight-Celotex under the trade name Celotex®.

The 9975 package is expected to perform its safety function for at least 12 years from initial packaging (2 years in transport + 10 years in storage). Due to a potential for degradation of the cane fiberboard over time in the KAMS storage environment, testing is being performed to validate satisfactory performance over this expected service life. While the shipping package design minimizes air infiltration, it does not provide a water-tight seal. Accordingly, the fiberboard can be exposed to changes in humidity in the surrounding air. This paper describes findings from baseline testing of both cane fiberboard and a wood-based fiberboard, after conditioning at specific temperature and humidity levels.

The cane fiberboard insulation used in 9975 packages meets ASTM C208-95, Grade IV wall sheathing. Layers of fiberboard are laminated together with water-based polyvinyl acetate (PVAC) adhesive. The cane fiberboard is composed of cellulose ($\leq$96%), starch ($\leq$10%), clay ($\leq$2%), carbon black (<0.5%), paraffin wax binder ($\leq$2%) and a lamination adhesive ($\leq$3.5%) [2].

The maximum ambient temperature in the KAMS storage areas under normal operating conditions is 120F. Thermal analysis of the 9975 package under steady state conditions shows (for a maximum internal heat load) the drum side fiberboard temperature is 13F above ambient and the maximum interior fiberboard temperature is 64F above ambient. Therefore, the maximum fiberboard temperature will range from 133F to 184F. Since the ambient environment can provide a relative humidity up to 100% (at 120F), and moisture can infiltrate the 9975 drum, the insulation can be exposed to moisture levels from 70% relative humidity (at 133F) to 20% relative humidity (at 184F), based on published psychrometric charts [3].

Test Plan

Samples of cane fiberboard and wood-based fiberboard were tested to provide baseline compressive and tensile strength in orientations parallel and perpendicular to the fiberboard layers. Mechanical testing was performed on ~2 inch cube samples (Figure 1). A limited number of larger samples (~5 inch cubes) were also tested to verify that the selected sample size will provide results applicable to the full insulation assemblies within the 9975 package. The samples were conditioned at a specific temperature and humidity for 2 weeks, and tested at the same temperature. The nominal environments selected for conditioning include temperatures of ambient (77F), 125F and 195F, and relative humidity levels of approximately 0%, 40% and 100%.

Conditioning of the samples was accomplished in one of three ways. For low humidity levels (~0%), the samples were placed in a sealed box with desiccant, and then heated to the specified temperature. In the case of 195F, no desiccant was used since the temperature alone ensures a very low humidity level. For high humidity levels (~100%), the samples were placed on a rack over water, in a sealed box, and then heated to the specified temperature. For the intermediate humidity level, an environmental chamber was used to maintain the specified temperature and humidity.

Mechanical testing (tensile / compression) was performed on a Sintech 4507 universal test machine with an oven to maintain the samples at the conditioning temperature during testing. As the samples were removed from their conditioning chamber, they were quickly weighed and measured, and placed into an insulated box lined with heated metal plates to maintain the sample temperature. They remained in this box until transfer into the test machine. In this manner, the samples were maintained at almost constant temperature throughout conditioning and testing. The humidity levels were not controlled after the samples were removed from the conditioning chamber, but the time between removal and testing was minimized (typically less than 1 hour to test all samples in the set) to maintain the samples at approximately constant moisture content. Both tensile and compression tests were performed with a crosshead speed of 2 inch/minute.

Tensile test samples had blocks glued to each end to provide a means of gripping the samples as described in ASTM C209. The blocks were attached with a moisture-cured polyurethane adhesive for ambient and 125F temperatures. A high temperature epoxy was used for samples tested at 195F. The wood blocks that were glued to the samples were conditioned with the samples to maintain a consistent moisture level. Since the polyurethane adhesive requires moisture to cure, the glue surface of each block was typically moistened before being glued to the sample. Blocks were typically glued to the samples 1 day prior to testing. The glue was allowed to cure for ~4 hours under clamping pressure before the samples were returned to the conditioning chamber to allow the samples to return to an equilibrium condition.

Weight and dimensional data were recorded for each sample before and after conditioning. In addition to the samples which were tested at temperature, several control samples were conditioned in each environment. After conditioning, the control samples were characterized, dried (in desiccant) at room temperature, and allowed to return to equilibrium at ambient temperature and humidity. These control samples were then characterized again and subjected to tensile and compression testing.

Test Results

Changes in dimensions and density resulting from the conditioning environment are summarized in Table 1. Mechanical test data are summarized in Tables 2-4. Summary stress-strain curves are shown in Figures 2-4.

Several observations can be made for both the cane fiberboard and wood-based fiberboard samples. For both materials, the tensile strength was much weaker for samples tested in the perpendicular orientation than for samples tested in the parallel orientation. Further, for both materials, the perpendicular samples tended to test in a plane along the layers of fibers, while the parallel samples tended to tear at ~45 degrees to the fiber layers.

The strength (both tensile and compressive) of both materials tended to decrease at elevated humidity (particularly 100%) and at elevated temperature. In contrast, most of the control samples which were conditioned at these extremes and then returned to ambient conditions prior to testing regained their lost strength. The exception to this is the control samples conditioned at 195F and 100% humidity. While these samples regained much of their lost strength, they remained the weakest of the control samples. This effect is illustrated in Figure 5. In addition to variation in strength with environment, multiple samples conditioned and tested in the same environment showed some sample-to-sample variation.

The compression samples tested in the parallel orientation exhibited an initial rise in load until the layers began to buckle (Figure 6). Using the maximum load prior to buckling, as well as the stress at 65% strain, to characterize the compressive behavior, the same trends are observed for these samples as for the tensile samples. Specifically, the strength is reduced at elevated humidity and temperature. While the compression samples tested in the perpendicular orientation did not exhibit a buckling behavior, the same trends in strength variation were observed for both types of fiberboard. While most of the perpendicular orientation samples compressed uniformly with no significant lateral spreading (Figure 6), the samples conditioned at 195F and 100% humidity (and some of the samples from 125F and 100% humidity) split apart at ~80% strain.

Discussion

In general, the density changes were very small for all samples except those conditioned at 100% humidity (all temperatures). Dimensional changes were greatest in the sample height (perpendicular to the fiberboard layers), with this one dimension accounting for the majority of the change in volume.

Figure 7 shows the change in visual appearance that resulted from conditioning at 195F, 100% humidity for 2 weeks. The samples from this environment were significantly darker in color and swollen in size. Samples conditioned in the other environments had a lesser degree of size change, and negligible color change.

The cane fiberboard samples were obtained from two sources. Most of these samples were machined from a single new 9975 package. The remainder was machined from the undamaged portion of several packages used for drop testing in 2000. The fiberboard density from the dropped packages is lower than that in the new package (~255 kg/m^3 vs ~310 kg/m^3).

The samples taken from the dropped packages were conditioned and tested at 125F (all humidity levels). It is seen from Table 3 that the compressive strength in the perpendicular orientation for these samples does not follow the trend for the other temperatures. Based on the storage conditions of the dropped packages, it was expected that all the samples tested would reasonably represent 9975 packages early in their service life. This variation for the dropped packages may represent variability between fiberboard batches, or an unanticipated effect of their storage conditions.

Several of the samples that were compression tested in the parallel orientation were photographed during testing. These photographs show that the mode of buckling and folding of the layers varies with the conditioning environment. (Refer to Figure 8.) Figure 8 shows a difference in failure mode during parallel orientation compression testing, depending on moisture content. The material tends to split or flake apart when the moisture content is low. Alternatively, with high moisture content, the layers are much more flexible and bend more readily. While this behavior was observed at all three test temperatures, it is more pronounced with higher temperature. In contrast, variation in the behavior of the control samples is reduced, with a degree of flaking observed for all control samples which were compression tested in the parallel orientation. This is illustrated in Figure 8(c). There is, however, a slight variation among the control samples. The samples previously conditioned at 195F (both low and high humidity) appear more prone to flake apart than the other control samples. While this difference is small, if it is real, it might reflect a degree of permanent degradation from the higher temperature exposure.

Additional evidence of permanent change in the material is seen in Table 5. This table summarizes the weight difference for the control samples from beginning of conditioning until they returned to ambient conditions. The control samples which were conditioned at 77F and 125F experienced a small net increase in weight. This increase is consistent with a general increase in ambient humidity during the summer when the final measurements were made. In contrast, the control samples conditioned at 195F (both high and low humidity) experienced a net decrease in weight.

The value of the wood-based fiberboard data are in demonstrating that the observed behaviors are common to a range of fiberboard products, and are not unique to a particular grade of cane fiberboard. Of greater relevance to the 9975 packages, it is expected that the actual Celotex material in the many packages in service will encompass a greater range in properties and behavior than that seen in the small number of packages tested. This additional data on the wood-based fiberboard provides a measure of confidence that the behavior which might be shown by the larger population of packages may not be significantly different from that measured.

Prior Mechanical Property Data

Mechanical properties of cane fiberboard have been characterized in the past [4-6]. These prior efforts included test temperatures ranging from -40 to 250F, but the samples were conditioned for 1 day or less prior to testing.

The data reported in Reference 4 was obtained from 2 inch cubes, while Reference 5 tested 2 inch cubes as well as ½ inch thick "dogbone" tensile samples. Reference 5 reports testing performed on Celotex material at several temperatures (-40F, ambient and 250F), with and without prior conditioning at 0 or 100% humidity. When used, the conditioning consisted of drying in an oven, or exposure to 100% humidity, for 24 hours. The samples were then brought to the specified test temperature and tested. Reference 6 similarly tested Celotex at temperatures of -40F, ambient and 150F. None of the Reference 6 samples were conditioned prior to testing. A further difference in the Reference 6 data from that of the other references is the test speed. These samples were tested at a crosshead speed of 0.1 inch/min. The Reference 4 data were generated with a crosshead speed of 2.25 inch/min. The Reference 5 data and the current data were generated with a crosshead speed of 2 inch/min.

Comparing these prior data to the current data, a number of similarities are seen. As with the current testing, strength is seen to vary with temperature and humidity. The range encompassed by the compressive strength of the prior data is compared to that of the current data in Figure 9. The range of compressive strength in the perpendicular orientation is significantly greater for the current data, primarily due to the samples conditioned at high humidity.

The Reference 5 data are the most complete set of prior information. Some variation is seen as a result of the different test temperatures and conditioning. In particular, the samples tested at ~ -40F were consistently the strongest, and the samples tested at 250F (especially those conditioned at 100% humidity) were the weakest. The total range of behavior of all the prior data shows a significant band of variation. The current testing further expands this band of variation.

Conclusions

Mechanical properties have been measured on cane fiberboard insulation material from 9975 packages and a similar wood-based fiberboard material. As expected, the mechanical properties were found to vary with the material orientation (loading parallel or perpendicular to the fiberboard layers), conditioning humidity, conditioning temperature, and sample variation. These parameters are listed in the order of effect – material orientation and humidity had the greatest effect on strength, while sample variation generally had the least.

References

[1] DOE-STD-3013-2000, "DOE Standard Stabilization, Packaging, and Storage of Plutonium Bearing Materials", September 2000.

[2] Material Safety Data Sheet 00040-85F, "Premium Fiberboard Insulation Sheathing, Manufactured Home USB, Coated 1 & 6 Sided", Knight-Celotex Fiberboard, April 19, 2002.

[3] Perry's Chemical Engineer's Handbook, Sixth Edition, McGraw-Hill Book Company, 1984.

[4] SRT-MTS-93-3119, "Packing Material Compression Tests", D. R. Leader, November 29, 1993.

[5] WSRC-TR-2000-00444, "Celotex Structural Properties Tests", A. C. Smith and P. R. Vormelker, December 2000.

[6] Y/EN-4120, "Packaging Materials Properties Data", M. S. Walker, Oak Ridge National Laboratory, January 1991.

Table 1. Summary of physical property changes for Celotex samples during conditioning.

Environment (Temp., RH,)	Relative Change during Conditioning (%)			
	Weight	Height	Volume	Density
77F 0%	-0.4	-0.2	-0.5	0.0
77F 40%	-0.4	-0.1	-0.6	0.3
77F 100%	15.8	7.4	9.3	5.8
125F 0%	-2.4	-0.7	-1.3	-1.2
125F 40%	-2.9	-1.1	-1.7	-1.2
125F 100%	24.6	9.9	9.9	12.9
195F 0%	-8.0	-2.7	-3.8	-4.5
195F 40%	-5.6	-3.8	-3.8	-2.0
195F 100%	22.0	9.1	11.1	9.6

Table 2. Maximum tensile strength of fiberboard samples. A range of values represents the variation from multiple samples.

	Cane Fiberboard Strength (psi)			Wood-based Fiberboard Strength (psi)		
	77 F	125 F	195 F	77 F	125 F	195 F
Parallel Orientation, as-conditioned						
0% RH	168 – 187	194 – 202	142 – 187	274 – 344	250 – 279	137 – 162
40% RH	193 – 208	139 – 175	106	344 – 369	157 – 261	119 – 166
100% RH	42 – 63	30 – 55	3 – 15	182 – 187	150 – 153	20 – 21
Parallel Orientation, control samples, after return to ambient temperature & humidity						
0% RH	159	163	173	356	326	333
40% RH	193	232	NA	342	339	314
100% RH	165	153	94	343	304	230
Perpendicular Orientation, as-conditioned						
0% RH	9 – 10	4 – 8	6 – 9	8 – 10	7 – 8	6 – 7
40% RH	4 – 5	6 – 8	NA	8 – 9	8 – 10	6
100% RH	3 – 6	NA	2	6 – 8	3 – 6	3 – 4

Table 3. Relative compressive strength of fiberboard samples, represented by the stress at 65% strain. A range of values represents the variation from multiple samples.

	Cane Fiberboard Strength (psi)			Wood-based Fiberboard Strength (psi)		
	77 F	125 F	195 F	77 F	125 F	195 F
Parallel Orientation, as-conditioned						
0% RH	590 – 654	509 – 657	382 – 476	359 – 602	670 – 821	459 – 735
40% RH	589 – 659	350 – 671	384	395 – 660	427 – 585	583 – 723
100% RH	206 – 247	76 – 78	87 – 104	497 – 575	317 – 360	314 – 345
Parallel Orientation, control samples, after return to ambient temperature & humidity						
0% RH	689	438	501	NA	NA	NA
40% RH	408	387	NA	NA	NA	NA
100% RH	528	NA	409	NA	NA	NA
Perpendicular Orientation, as-conditioned						
0% RH	1807 – 2006	1018 – 1132	2090 – 2338	3861 – 4153	4592 – 4892	3282 – 3362
40% RH	1837 – 1952	907 – 1080	1741	3543 – 3628	2970 – 3241	2314 – 2691
100% RH	554 – 586	97 – 344	280 – 292	2247 – 2374	1182 - 1311	747 – 1193
Perpendicular Orientation, control samples, after return to ambient temperature & humidity						
0% RH	1584	1363	1662	NA	NA	NA
40% RH	1769	1816	NA	NA	NA	NA
100% RH	1233	1507	1106	NA	NA	NA

Table 4. Relative compressive strength of fiberboard samples, represented by the maximum stress prior to buckling. A range of values represents the variation from multiple samples.

	Cane Fiberboard Strength (psi)			Wood-based Fiberboard Strength (psi)		
	77 F	125 F	195 F	77 F	125 F	195 F
Parallel Orientation, as-conditioned						
0% RH	248 – 269	226 – 238	172 – 264	347 – 410	264 – 278	220 – 228
40% RH	265 – 295	240 – 256	273	333 – 350	249 – 279	163 – 182
100% RH	62 – 72	28 – 31	25 - 28	189 – 228	99 – 112	74 – 86
Parallel Orientation, control samples, after return to ambient temperature & humidity						
0% RH	250	221	235	NA	NA	NA
40% RH	203	241	NA	NA	NA	NA
100% RH	197	NA	155	NA	NA	NA

Table 5. Average weight change of control samples from preconditioning to pretest. During this interval the control samples were conditioned for 2 weeks in the specified environment, dried in desiccant, and returned to ambient conditions.

	Average weight change (%)		
	0% Humidity	40% Humidity	100% Humidity
77F	0.5	0.4	1.5
125F	0.1	0.1	1.3
195F	-0.4	- - -	-2.5

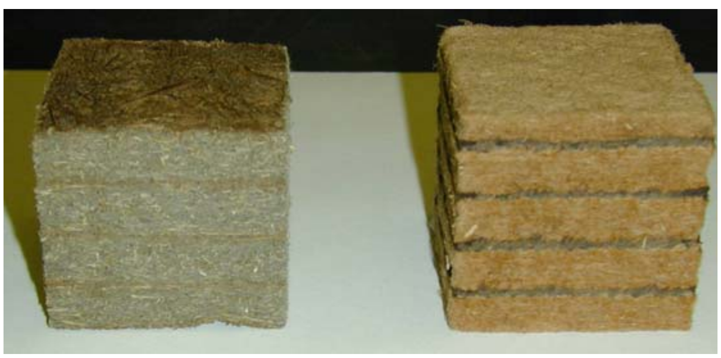
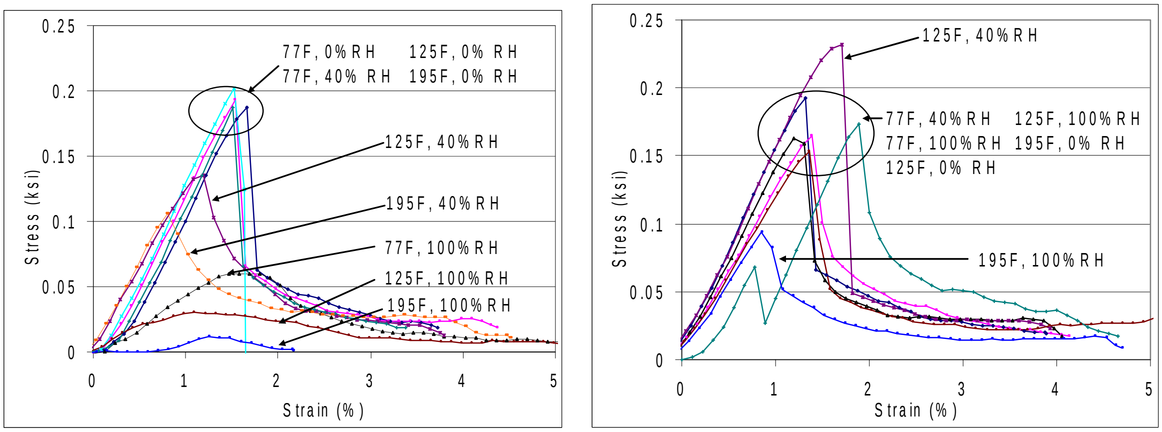
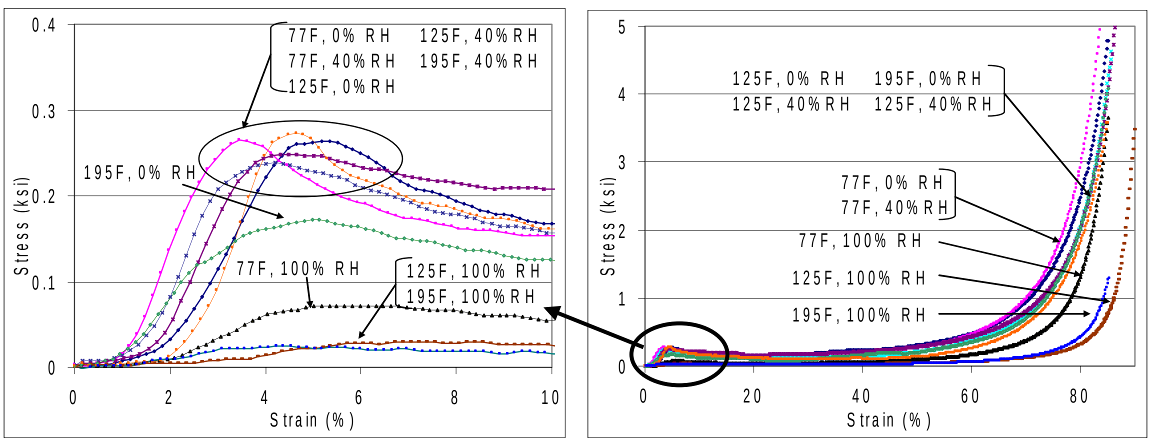


Figure 1. Cane fiberboard (left) and wood-based fiberboard (right) 2 inch cube samples. The samples differ in color, texture and inter-layer joint thickness.

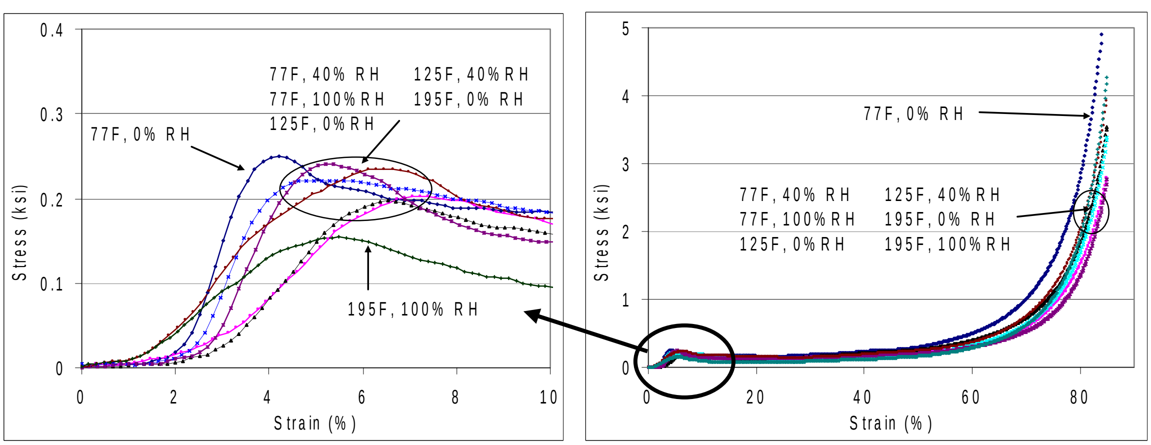


(a) As-conditioned (b) Control samples, following return to ambient

Figure 2. Summary tensile data, parallel orientation, for typical cane fiberboard samples.

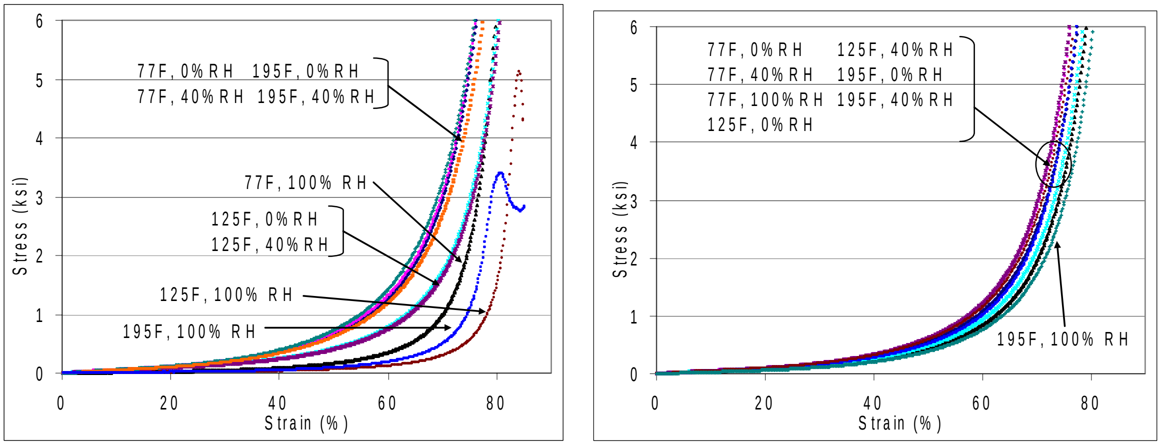


(a) As-conditioned



(b) Control samples, following return to ambient

Figure 3. Summary compression data, parallel orientation, for typical cane fiberboard samples.



(a) As-conditioned (b) Control samples, following return to ambient

Figure 4. Summary compression data, perpendicular orientation, for typical cane fiberboard samples.

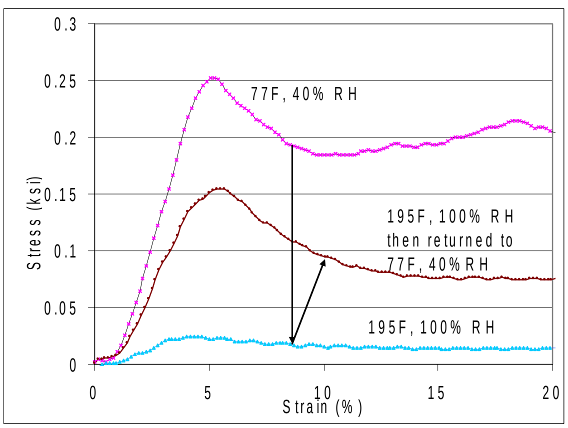
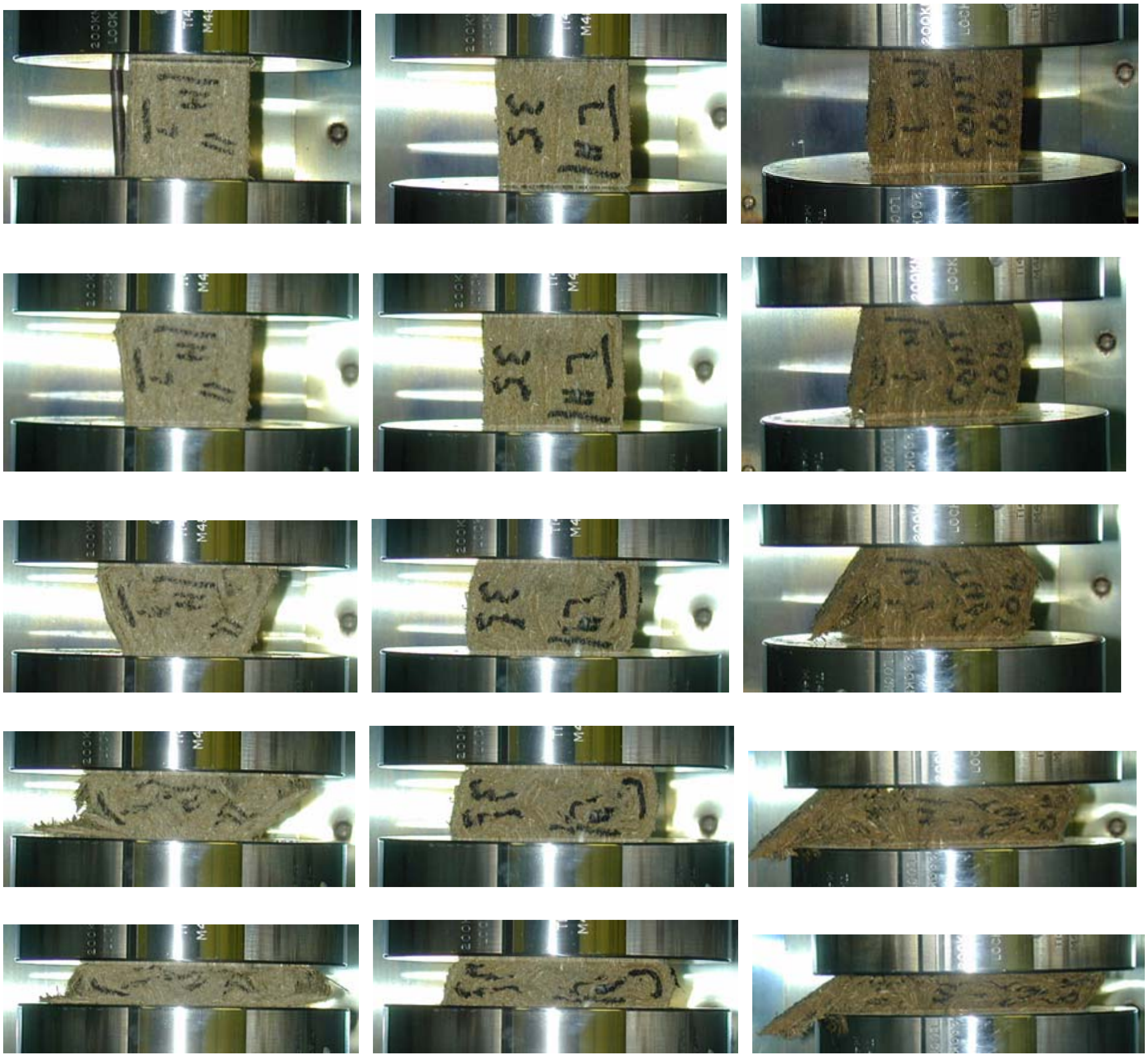


Figure 5. Effect of prior conditioning on compression strength (parallel orientation) at ambient temperature and humidity. Only the low strain portion of the curve is shown for clarity. A similar effect is seen at higher strain, but to a lesser degree.

(a) (b)

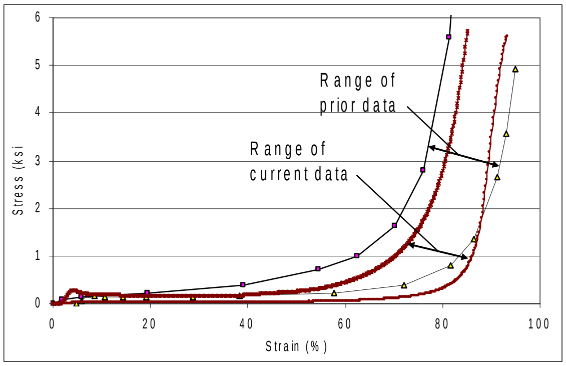
Figure 6. Typical cane fiberboard samples after compression testing (parallel orientation (a) and perpendicular orientation (b)). Both samples were conditioned at 195F, 0% humidity.

Figure 7. Effect of conditioning at 195 F 100% humidity for 2 weeks. The sample on the right was conditioned in this environment, while the sample on the left was not conditioned. The conditioned sample has increased in height by 0.1 inch (5%) due to moisture absorption.

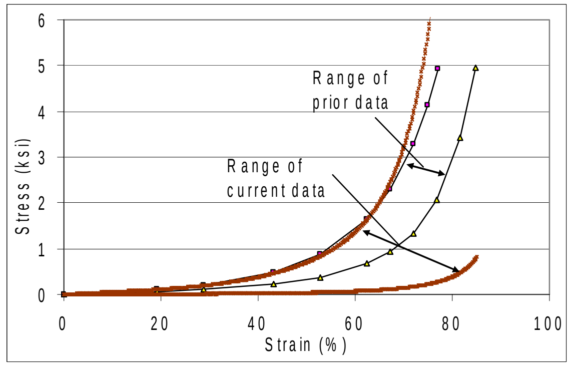


(a) (b) (c)

Figure 8. Photographs during compression testing (parallel orientation) of samples conditioned at 77F 0% humidity (a) and 77F 100% humidity (b). The sample in (c) was conditioned at 195F 100% humidity followed by exposure to ambient temperature and humidity.



(a) Parallel direction



(b) Perpendicular direction

Figure 9. Comparison of total range of compression data from prior and current testing.