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DEGRADATION OF FIBERBOARD IN MODEL 9975 PACKAGE FOLLOWING ENVIRONMENTAL CONDITIONING – FIRST INTERIM REPORT

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Summary

Fiberboard material, used in the 9975 shipping package, has been tested for thermal, mechanical and physical properties following environmental conditioning for periods up to 64 weeks. The environments are either representative or bounding of KAMS storage conditions, in order to provide prediction of long-term performance of the 9975 package in KAMS. This report summarizes the data and analysis performed to date. These data show degradation of some properties in some of the environments, but samples have not degraded beyond identified minimum KAMS requirements. Statistical analysis of the data collected to date support the development of a model to predict a service life in KAMS. Further model development and lifetime predictions will be made following additional conditioning and testing in accordance with the task technical plan.

Background

Celotex® fiberboard material is used in the 9975 shipping package between the outer 304L stainless steel drum and the lead shielding, and provides three safety functions: thermal insulation to limit internal temperature during a fire, criticality control and resistance to package crushing [1]. Celotex® material is cane fiberboard insulation specified by ASTM C208-95 as cellulosic fiber insulating board, Type IV, Grade 1 wall sheathing. The range of environments which fiberboard in KAMS can experience is illustrated in Figure 1. Also shown in this figure is the range of fiberboard environments under loss of ventilation (including natural convection) conditions.

The fiberboard material must retain its dimensions and density within certain ranges to provide the required impact resistance, criticality spacing and fire resistance. Several properties of interest to demonstrate acceptable long-term performance of the material include dimensional stability, moisture absorption/retention, density, compressive strength, thermal conductivity and specific heat capacity.

Baseline testing of mechanical and thermal properties has been performed [2, 3]. The baseline thermal tests were performed at temperatures of 25, 51 and 91ºC (77, 125 and 195ºF) with no prior conditioning of the samples. Conditioning the baseline thermal test samples immediately prior to testing was not practical since the samples were sent to an offsite vendor for testing. Moisture content was not controlled during these tests – the samples would have been in approximate equilibrium with ambient humidity at the time of the test. The baseline mechanical tests were performed at the same three temperatures, but the samples were conditioned at their respective test temperature for 2 weeks prior to test. In addition, the humidity level during the conditioning was controlled at ~0%, ambient or ~100% relative humidity for different sample sets during the 2 week conditioning period.

Following the baseline testing, a test matrix was identified for longer term conditioning and testing of thermal and mechanical properties [1]. Conditioning periods up to 16 weeks were identified for a number of environments. Conditioning for longer periods would continue, depending on results from the defined test matrix.

Longer-Term Testing

The longer-term testing includes conditioning in several environments that either approximate or bound the range of KAMS environments. These are illustrated in Figure 1. The 102ºC (215ºF) environment was added following a preliminary examination of early data, to provide an additional environment within the range where significant degradation was observed (i.e. 85 and 121ºC (185 and 250ºF)). Both compression and thermal conductivity samples were placed in this environment. The 71ºC (160ºF) environment was originally planned to maintain a relative humidity of 40%. After the environmental chamber had difficulty maintaining this humidity level, 50% relative humidity was established and used instead.

The longer term testing used test samples from several different packages, identified as follows:

- LD1 – lower assembly, drop tested package #1
- LD2 – lower assembly, drop tested package #2
- MSC – miscellaneous upper and lower assemblies (assemblies were cut up and individual identities lost before the importance of material source was noted)
- KT2 – KAMS-TEST-2 lower assembly (used for the original baseline data)
- 2234, 826 – lower assemblies from KAMS surveillance packages 9975-02234 and 9975-00826 following destructive examination

The planned test matrix with conditioning periods up to 16 weeks has been completed. With several of the environments dependent on the use of a single environmental chamber, these environments have typically just completed the scheduled intervals. In contrast, samples conditioned in ovens (~0% humidity) have completed exposures much greater than 16 weeks since several ovens are available to condition multiple sets of samples in parallel. When the samples in the ovens completed the planned (16 week) exposures, test objectives for the remaining samples in those environments were reviewed, and test plans were revised to include longer exposure periods [4].

Following an extended period of conditioning samples at 121ºC, the samples were transferred to a different oven (at the same temperature). It was then observed that the rate of weight loss for some of the samples was different in the two ovens. The first oven was then re-loaded with samples approximating the original set of samples, and the temperature verified with an independent thermocouple. It was observed that this oven developed a significant temperature gradient, with temperatures varying from 116 to 148ºC. Thermal conductivity sample LD2-1A was in the hottest region, and probably had a significant gradient through its thickness. The mass loss samples were in a region slightly cooler than 121ºC. Additional detail on the actual temperature each sample experienced will be reported following further analysis of the data.

During performance of the test matrix, several changes were made based on ongoing results or input from the customer. These changes were documented in the laboratory notebook [5] and are described below. The following test data have been collected during this period.

Compression Testing
Table 1 lists samples that were compression tested following environmental exposures up to 16 weeks. Table 2 lists samples that have been tested, or are planned for testing, following environmental exposures greater than 16 weeks.

Additional compression samples from some of the material sources were added to several environments after the observation of different behavior for the various sources. An additional material source was also added to select environments –N (new fiberboard assembly purchased under a separate effort).

Thermal Testing
Table 1 lists thermal test samples that were tested following environmental exposures up to 16 weeks. Table 2 lists samples that have been tested, or are planned for testing, following environmental exposures greater than 16 weeks.

Specific heat capacity testing at a mean temperature of 85ºC was dropped due to inconsistent results, caused in part by cycling the test apparatus between multiple test temperatures. Mean test temperatures of 25 and 51ºC were retained. A greater degree of scatter is still observed in the 25ºC mean temperature data than in the 51ºC data, and the 25ºC mean temperature data appear to be biased high. However, the collective data for each mean temperature provide a means for trending and identifying degradation of properties.

Specific heat capacity and thermal conductivity samples conditioned at 51ºC (dry oven) were added.

Dimensional and Density Measurements
As identified in Reference 1, samples have been conditioned at several elevated temperatures in order to track dimension, weight and density changes. This was prompted by samples conditioned at 91ºC which experienced weight loss beyond that which moisture loss would explain. Dimension and weight data have been collected at 71, 85, 93, 102 and 121ºC. The samples for 85 – 121ºC environments were conditioned in a (nominally dry) oven. The 71ºC samples were at 50% relative humidity, and additional samples have recently started conditioning at 85ºC 70% relative humidity. The samples continue to be tracked in most of these environments.

A limited number of samples began conditioning at low temperature (approx. -10 and 10ºC / 14 and 50ºF) to determine if dimensions or density change at low temperature. At 10ºC, samples were conditioned dry (with desiccant), at ambient humidity, and at ~100% humidity. At -10ºC, samples were conditioned dry (with desiccant) and at ambient humidity. These low temperature samples were added at the request of the customer.

As a comparison to these data, the weight and dimensions of compression and thermal conductivity samples are recorded prior to testing. The compression samples are measured only twice (prior to conditioning and prior to testing), while the thermal conductivity samples are measured a number of times since they are tested repeatedly. The limited handling of these samples would provide less opportunity for inadvertent weight loss due to "shedding" during handling.

Three fiberboard upper subassemblies were weighed and measured periodically during the baseline testing. This effort has continued. Following the accumulation of greater than 12 months data, and establishing the seasonal variation in these measurements, one of the upper subassemblies was placed back inside its drum and removed only for monthly measurement. Subsequently, a second upper subassembly was placed back inside its drum and will be removed for measurement after a much longer interval. This is intended to identify the degree of isolation provided by the drum.

Test Data

Compression Data

Engineering stress strain curves are shown in Figures 2 – 11 for fiberboard samples following environmental conditioning. Data for environments with a controlled humidity (50 or 70% relative humidity) are given in Figures 2-5. Data for dry environments are given in Figures 6-9. Figures 10 and 11 show representative data for samples that were cycled between two environments (varying either the temperature or humidity).

Given the variation in the shape of the stress-strain curves, particularly for samples tested in the parallel orientation, several numerical parameters were selected to provide comparison between samples and identify overall patterns of degradation. For all samples, the area under the stress-strain curve up to a strain of 40% was calculated, representing the energy absorbed to that point. Both the energy absorbed and the stress at 40% strain were tabulated. In addition, the buckling stress was identified for samples tested in the parallel orientation. This is the stress at which the fiberboard layers begin to buckle, and is generally marked by a local peak in the stress-strain curve. These comparative data for samples conditioned in a single environment are listed in Tables 3 (parallel orientation) and 4 (perpendicular orientation).

Thermal Data

Unlike mechanical testing, the thermal conductivity and specific heat capacity tests are nondestructive. A small number of samples are used for these tests, and are returned to the conditioning environment for continued exposure. Each set of thermal samples is typically tested every 8 weeks. In general, 4 thermal conductivity samples were conditioned in each environment, and each sample was tested at each test interval. The thermal conductivity is measured at mean temperatures of 25 and 50ºC for all samples. In addition, the samples conditioned at 71ºC are also tested at that mean temperature (71ºC), and the samples conditioned at 85ºC or higher are also tested at 85ºC. 85ºC is the highest mean temperature the test instrument can achieve. Thermal conductivity data are summarized in Figure 12.

Initially, specific heat capacity testing was performed on 3 samples from each environment (out of 5 samples typically conditioned in each environment). As specific heat capacity data was being collected, a degree of sample-to-sample variation was indicated, although significant overall scatter was also observed. Subsequently, all specific heat capacity samples in each set were tested at each test interval. The mean test temperatures for all samples were also restricted to 25 and 52ºC. This was found to reduce the scatter somewhat. The specific heat data are summarized in Figure 13.

Dimensional and Density Data

Dimensional and weight information have been collected on several samples in a number of environments. These data allow calculation of the material density. Samples that were placed in the environments specifically to identify weight and/or density changes are measured weekly for elevated temperature environments, and are measured monthly for low temperature environments. In addition, thermal conductivity samples are weighed and measured prior to each test, and they provide additional data on physical changes over time. Compression test samples are also weighed and measured prior to testing, but since the compression test is destructive, each compression sample provides only a single datum, and sample to sample variation limits the usefulness of physical data from these samples. Each of these three sources of physical properties can be compared against each other for consistency. The samples that are handled the most (the mass loss samples) provide the most data, but are also most prone to incidental mass loss from handling. Comparing these data to that from samples handled less often should provide a bound on that effect.

Weight change over time for mass loss samples and thermal conductivity samples is shown in Figures 14 – 21. These data are for conditioning temperatures from -10 to 121ºC. In some cases, the humidity level was controlled to a specific value, or allowed to vary with ambient conditions. In most cases, the relative humidity was low due to the elevated temperature. Corresponding density change over time for mass loss and thermal conductivity samples is shown in Figures 22 – 29.

In comparison to the weight change noted for mass loss and thermal conductivity samples, weight change data for compression test samples are shown in Figure 30. These data display greater scatter due to sample variation, but show a similar degree of weight loss for each environment.

The weight and dimensions of three upper fiberboard subassemblies have been tracked for over a year. All three subassemblies have been in the same (ambient) environment and displayed the same seasonal variations in weight. After the degree of seasonal variation was established, one subassembly was returned to its 9975 drum and continued to receive regular measurements. The degree of weight variation decreased significantly. To further quantify the degree of isolation provided by the drum, a second subassembly was returned to its 9975 drum and will not be measured until the seasonal variations in the third subassembly reach a maximum or minimum value. Comparing these subassemblies should indicate the degree of air/moisture exchange provided by the closed drum versus the degree of air/moisture exchange provided each time the drum was opened for measuring the subassembly.

The weight variations of the three upper subassemblies are shown in Figure 31. Subassembly volume variation is shown in Figure 32. Due to the presence of the air shield, some of the fiberboard dimensions cannot be measured. The dimensions that are measured are sufficient to calculate the volume of fiberboard below (as oriented within the drum) the aluminum bearing plate. Due to combined errors in dimension measurement, and the variation inherent in measuring a relatively soft porous material, the calculated volume shows a greater degree of scatter than the subassembly weight. Nevertheless, it provides a relative measure of the seasonal volume change. This seasonal volume change is consistent with the seasonal weight change in both magnitude and direction.

General Observations

In addition to the specific data mentioned above, there are several general observations to note. The visual appearance of many samples changed during conditioning, particularly at the higher temperatures and/or elevated humidity. The most obvious visual change is a darkening of the sample. Some of the samples at 121ºC also developed very dark spots across their surface. After extended periods at elevated temperature (particularly at 121ºC) and low humidity, samples typically developed a feel of being weak and brittle. For compression samples, this also corresponded to a tendency for the sample to fracture and split apart when tested in the perpendicular orientation, and at longer conditioning periods compression samples tested in both orientations tended to crumble to a powder rather than maintain the integrity of individual fibers. Some of these conditions are shown in Figures 33 - 36.

Each of the various sample types typically contains a few glue joints between fiberboard layers. Layer separation occurred in several samples to varying degrees (Figure 37). The general observation is that the extent to which the layers were initially bonded together can vary significantly, and the more weakly bonded joints tend to separate as the material dries and experiences shrinkage stress. In a few samples, layers completely separated (i.e. the sample separated into 2 sections). These samples were re-glued with Carpenters ™ yellow wood glue, similar to that used originally to laminate the assemblies. Where partial separation did not interfere with subsequent handling and testing, the separation was left as is.

One of the thermal conductivity samples conditioned at 121ºC was noticeably warped after 16 weeks, and remained so through 56 weeks. This sample did not flatten when placed between the platens of the thermal conductivity instrument. At 56 weeks, it was reduced in size from ~12 x 12 inches to ~7 x 7 inches (Figure 38). This eliminated a large degree of warpage such that the platens would come closer to contacting the full surface. The material cut easily with a knife, with no resistance from the glue joints or individual fibers. The material was very crumbly, and material came off as a powder when the edges were scraped. It was later recognized that this sample (LD2-1A) was at a location within the oven which was significantly hotter than 121ºC. A significant temperature gradient across the sample likely caused the warping, although a period of operation with the sample turned upside down did not noticeably reduce the warping.

During the baseline testing [2], foreign material (small rocks) was observed within the fiberboard material. During subsequent testing, additional foreign material, including glass and aluminum can fragments, has been observed within various samples (Figure 39). Samples in two environments have been observed with mold growing on them; ambient temperature 100% relative humidity, and 10ºC 100% relative humidity. No mold has been noted at 51ºC and higher, or at any temperature with lower humidity levels.

Statistical Analysis of Data

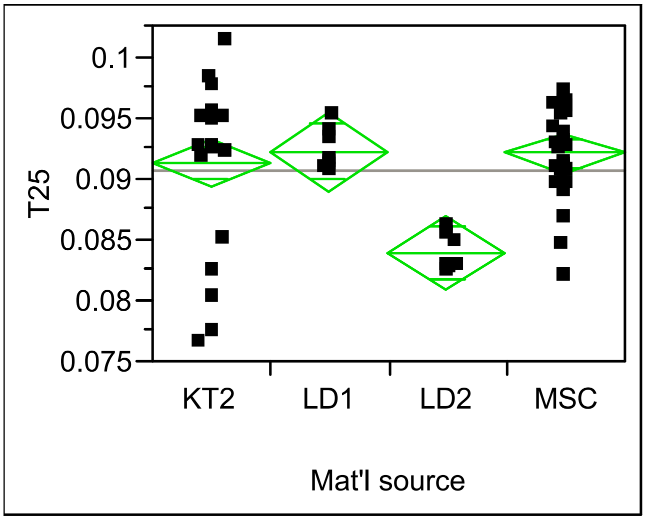
Fiberboard samples were conditioned at different levels of temperature, humidity and time using several different sources of material according to a statistical design strategy. Measurements were made on the mechanical, thermal and physical fiberboard properties of the samples over time. The statistical analysis of these data was conducted using the JMP statistical software. JMP (Ver. 5.1.2) is commercially available statistical software from the SAS Institute, Cary, NC. Fiberboard performance data consisted of measurements on thermal conductivity, specific heat capacity, compression tests (buckling strength, area to 40% strain, stress at 40% strain) and mass loss samples.

The data were screened for outliers (about 2%) and in addition all data records corresponding to time=0 (pre-conditioning) were deleted because of the step-change in moisture content incurred when conditioning begins. The resulting data were summarized using mean diamonds and descriptive statistics. The statistical modeling results were typically displayed using profile plots that show the impact of the conditioning factors (temperature, humidity and time) on the performance measures of the fiberboard samples. The prediction profile plots were based on statistical regression models developed by relating the performance data to sample conditioning parameters while accounting for the effect of sample or material differences. Partition analysis, a model-free approach to data analysis, was used on the specific heat capacity (SHC) data since they did not lend to regression modeling. In particular, the models fit to the SHC data based on the conditioning parameters data did not explain much of the variability in the data (R^2<24%). Therefore they should not be used for prediction of SHC.

Mean Diamonds

Graphical comparisons are presented using *mean diamonds* illustrating the material performance means and their corresponding 95% confidence intervals (Exhibit 1). The line across the mid-part of each diamond represents the group (Material Source) mean. The vertical span of each diamond represents the 95% confidence interval for each group using the pooled variance among the different groups. Overlap marks are also shown above and below the group mean. For groups with approximately equal sample sizes, overlapping marks indicate that the means for the two groups are not significantly different with a false positive error rate of 5% $(i.e.: p \le 0.05)$. The mean diamonds in Exhibit 1 are displayed only for illustrative purposes. Differences in means and variability could be due to sample conditioning by temperature, humidity, time or material source. The impact of these conditioning factors was investigated using statistical analyses.

Exhibit 1
Thermal Conductivity at 25°C (T25) by Material Source for the Radial Orientation

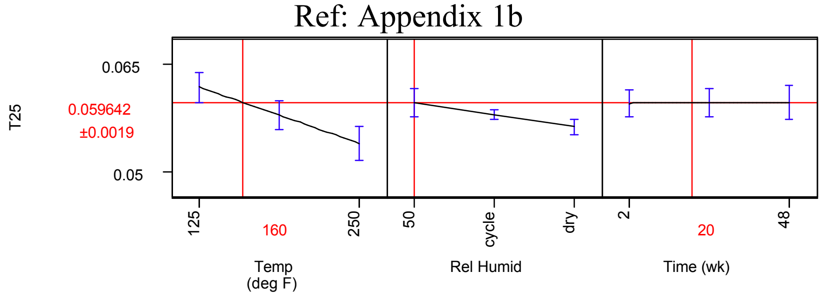


T25 Means and Standard Deviations

Material	Number	Mean	Std Dev	Lower 95%	Upper 95%
KT2	22	0.091	0.0067	0.088	0.094
LD1	8	0.092	0.0017	0.091	0.094
LD2	9	0.084	0.0015	0.083	0.085
MSC	29	0.092	0.0036	0.091	0.094

Prediction Profiles
The prediction profile in Exhibit 2a, for example, is a display of the predicted thermal conductivity at 25ºC (T25) as one process parameter is changed while the others are held constant at the current values. Prediction profiles, available interactively in JMP, are especially useful in handling multiple-response models (e.g.: T25, T51 and T85) for determining the effect of test parameters.

Exhibit 2a
Prediction Profile
Thermal Conductivity (W/m-K) at 25ºC for Axial Orientation
Ref: Appendix 1b



Conditioning at 71ºC, 50% Relative Humidity, and 20 weeks
Predicted T25=0.0596

- The low and high values for the test parameters are shown on the horizontal axis. The vertical red line for each test parameter shows its current value or current setting.
- For each test parameter, the value above the factor name is its current value.
- The horizontal dotted line shows the current predicted value for the current values of the test parameters.

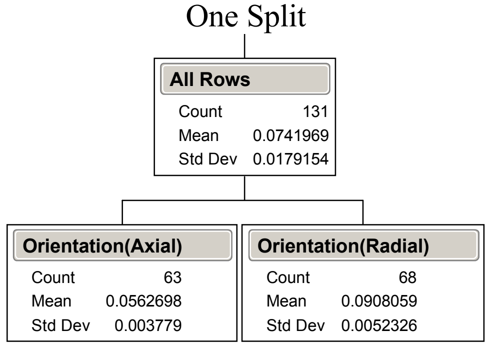
- The lines within the plots show how the predicted value changes when the conditioning parameter is changed.
- The prediction profile displays the effect on the predicted response of changing one process parameter at a time.
- The importance of a factor can be assessed to some extent by the steepness of the prediction curve.

If there are interaction effects or cross-product effects in a model, the prediction curves can shift their slope and curvature as the current values of the test parameters are changed. If there are no interaction effects, the prediction curves only change in height, not slope.

Partition Analysis

The Partition Analysis splits the data to maximize the difference in the responses between the two branches of the split (e.g: Exhibit 2b). Variations of this technique go by many names and brand names: decision trees, CART™, CHAID™, C4.5, C5, and others. The technique is typically considered to be a data mining method. It provides for exploring relationships without specifying a model while providing very interpretable results.

Exhibit 2b
Partition Analysis of
Thermal Conductivity (W/m-K) at 25ºC
One Split



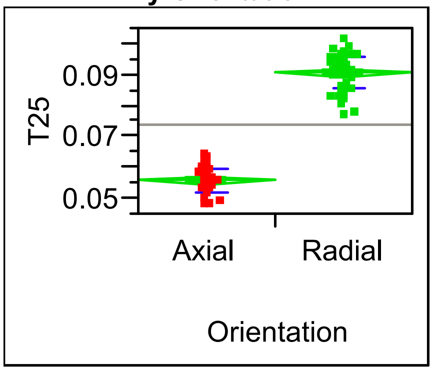
Statistical Results

Thermal Conductivity

Fiberboard samples for thermal conductivity testing were assigned to two orientations: axial and radial. Thermal conductivity measurements (T25, T51 and T85) were taken at 25, 51 and 85ºC. Mean diamonds and summary statistics are displayed in Exhibits 3a, 3b and 3c for T25, T51 and T85, respectively. The thermal conductivity for the radial orientation is about 60% higher on average than for the axial orientation regardless of the temperature at which the measurement was made. In addition, there is some indication that the variation is greater for the radial orientation for both the T25 and T85 data sets so the data for the axial and radial orientations were analyzed separately (Appendices 1 and 2). The thermal conductivity data for T25, T51 and T85 for each orientation are highly correlated (Appendix 1a, 2a: approximately greater than 98%) so that similar statistical results were expected and obtained after conducting the regression analyses. The model similarity can be seen in the profile plots Plots 1a and 1b for the axial and radial orientations, respectively. The impact of the material source could not be adequately evaluated for the axial location since the majority of samples (78%) were from the MSC source and the remaining samples were distributed among three other sources with different conditioning parameters (Humidity, Time & Temperature). Material source (KT2, LD1, LD2 and MSC) played a significant role in the radial tests as seen in the profile plots (Plot 1b). The LD1 and LD2 sources have lower thermal conductivity than the KT2 and MSC sources used in the radial tests (e.g.: Appendices 2b and 2c). The profile plots show that conditioning temperature over the range 51ºC to 121ºC is a primary factor influencing thermal conductivity for both axial and radial orientations. Higher conditioning temperature gives rise to lower thermal conductivity (T25, T51 and T85). Thermal conductivity is also seen to decrease over time for fixed conditioning temperature for the radial oriented samples but to a much lesser extent than for temperature. The impact of time on thermal conductivity is essentially non-existent for the axial orientation. Specifically, the impact of conditioning time for the axial samples is not significant for T25 and T51 and is barely significant for T85 ($p=0.03$). The impact of humidity is significant for T25 ($p=0.006$) from the axial samples and of minor significance for the others ($p>0.02$).

Exhibit 3.a

Thermal Conductivity at 25°C (T25) By Orientation

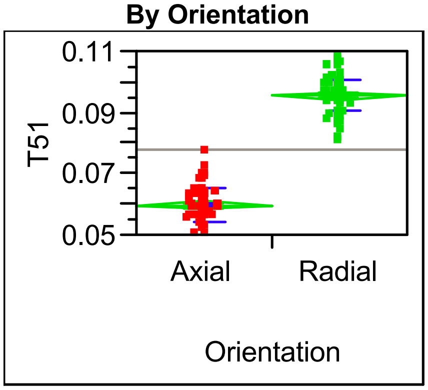


T25 Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Axial	63	0.056270	0.003779	0.05532	0.05722
Radial	68	0.090806	0.005233	0.08954	0.09207

Exhibit 3.b

Thermal Conductivity at 51°C (T51) By Orientation

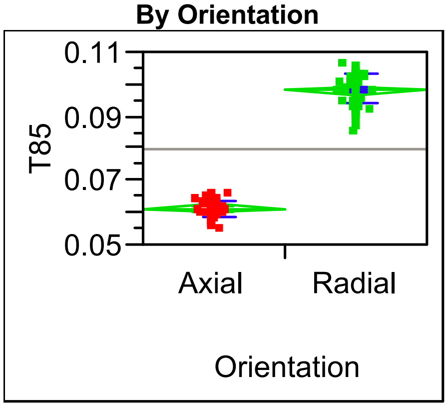


T51 Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Axial	69	0.060062	0.005019	0.05886	0.06127
Radial	74	0.095672	0.005666	0.09436	0.09698

Exhibit 3.c

Thermal Conductivity at 85°C (T85) By Orientation



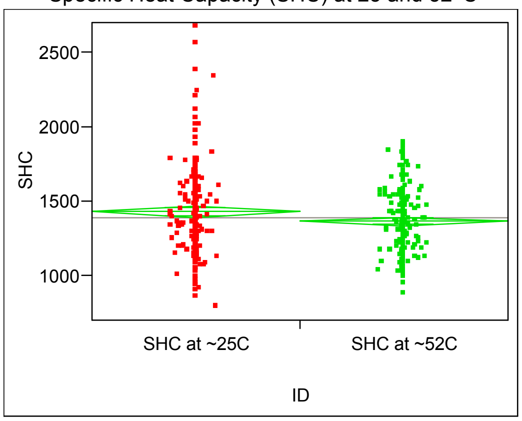
T85 Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Axial	48	0.061567	0.002630	0.06080	0.06233
Radial	47	0.098279	0.005085	0.09679	0.09977

Specific Heat Capacity
Specific heat capacity tests were conducted using the MSC samples. Other material sources were not conditioned. The specific heat capacity (SHC) was measured at two different temperatures: 25ºC and 52ºC on the same samples (Exhibit 4). There is not a significant mean difference between the 25 degree data and the 52 degree data ($p=0.065$) using a paired t-test (*t-test not displayed*). Further testing did not reveal a difference among the individual MSC samples ($p=0.48$). However, the correlation between the SHC at 25 and 52ºC was extremely weak (22%) so a separate analysis was done for each temperature.

Exhibit 4

Specific Heat Capacity (SHC) at 25 and 52°C



SHC Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
SHC at ~25C	188	1433.75	299.581	1390.6	1476.9
SHC at ~52C	247	1367.96	205.841	1342.2	1393.8

The partition analysis for SHC at 25ºC (Appendix 3a) indicated that humidity is the most influential factor for the SHC variability with duration (weeks) being a factor of lesser importance for combined cycle and 50% humidity samples. The data were split into two groups: 1) Humidity=0 and 2) Humidity=50% & Cycled for regression analyses. Conditioning time (Duration) was significant and conditioning temperature was not significant for both data sets (Appendices 3b and 3c). However, the trends relative to conditioning time were not consistent. In any event, the amount of variation explained by the models is minimal: 7% for data set 1 and 18% for data set 2.

The partition analysis for SHC at 52ºC (Appendix 4a) indicated that duration is the most influential factor for the SHC variability with humidity being a factor of lesser importance. The data were split into three groups: 1) Humidity=0 and 2) Humidity=50% and 3) Humidity= Cycled for regression analyses. The effect of conditioning temperature was not significant. However, the effect of duration was significant but the trends across the different data sets were not consistent among the three data sets (Appendices 4b, 4c and 4d). A model was not fit to SHC at 52ºC for data set 2 (Humidity=50%) because duration only spanned a four week period. As for the SHC at 25ºC, the amount of variation explained by the models for the SHC at 52ºC data sets 1, 2 and 3 is minimal (9%, n/a, and 24%).

The primary conclusion from the SHC data analysis is that humidity, duration and conditioning temperature are not adequate predictors of SHC performance.

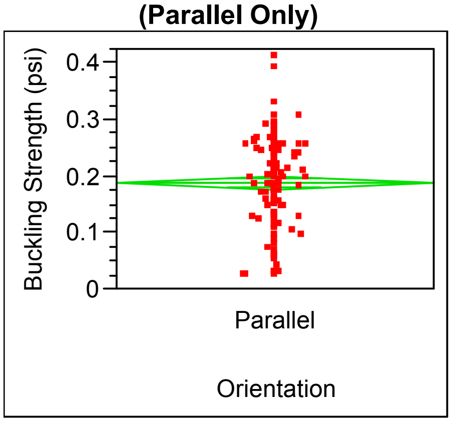
Compression Test Data

Samples with both parallel and perpendicular orientations were tested for Area to 40% strain and Stress at 40% strain. Buckling strength was tested for only parallel-oriented samples. The mean diamonds and summary statistics are displayed in Exhibits 5a, 5b and 5c for buckling strength, Area to 40% strain and Stress at 40% strain, respectively.

Separate statistical analyses were conducted for each orientation (Appendix 5). The profile plots for buckling strength, area to 40% strain and stress at 40% strain are displayed in Plots 2a and 2b for the parallel and perpendicular orientation, respectively. These profile plots were based on the regression models developed in Appendix 5. The amount of variation explained by the conditioning parameters and sample source terms is R^2=67% for breaking strength. The R^2's for Area to 40% strain and Stress at 40% strain for the parallel samples are 51% and 35%, respectively, while the corresponding values for the perpendicular samples are 73% and 70%. The source of material has a significant impact on the test results comparable to any of the conditioning factors. Buckling strength decreases as temperature, humidity or duration is increased. In addition, Area to 40% strain and Stress at 40% strain decreases as temperature, humidity or duration is increased for both parallel and perpendicular orientations.

Exhibit 5a

Buckling Strength (psi) By Orientation (Parallel Only)

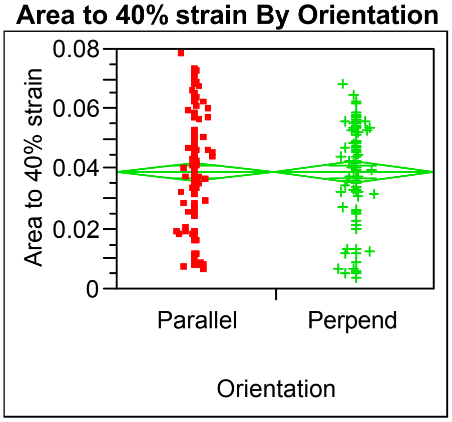


Buckling Strength Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Parallel	135	0.189496	0.074472	0.17682	0.20217

Exhibit 5b

Area to 40% strain By Orientation

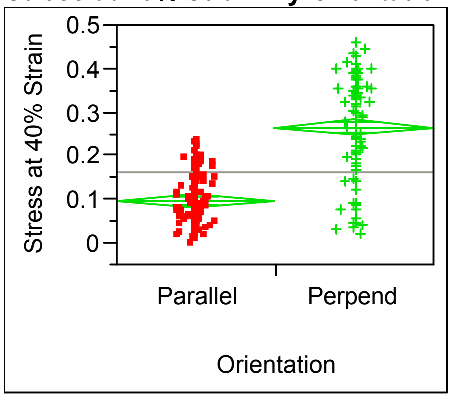


Area to 40% strain Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Parallel	135	0.039364	0.016364	0.03658	0.04215
Perpend	86	0.039335	0.016288	0.03584	0.04283

Exhibit 5c

Stress at 40% Strain By Orientation



Stress at 40% Strain Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
Parallel	135	0.098667	0.054799	0.08934	0.10799
Perpend	86	0.267802	0.115280	0.24309	0.29252

Mass Loss Results

Two metrics were used to investigate mass loss as a function of the conditioning parameters. They were based on the weight change and the density change of the samples relative to the initial value providing that time is greater than zero. Algebraically,

Fraction Weight Loss at time t=1- (Weight at time t)/(Initial Weight)

and

Fraction Density Loss at time t=1- (Density at time t)/(Initial Density)

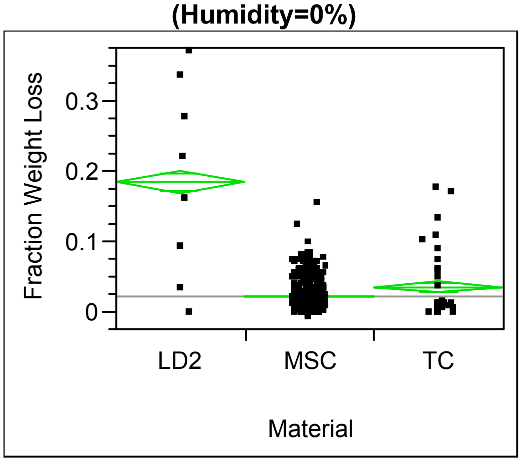
for each sample.

The initial values were based on deleting all time=0 records and then selecting the weight and density corresponding to the minimum time for each of the samples.

Statistical results for mass loss were based on using the MSC material source since the MSC material source accounted for about 97% of the conditioning tests conducted (Exhibit 6a, 6b).

Exhibit 6a

Fraction Weight Loss By Material (Humidity=0%)

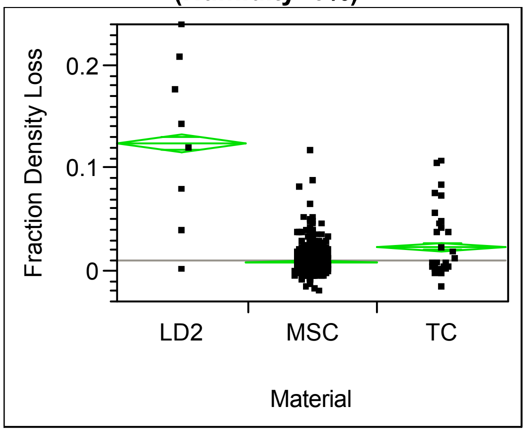


Fraction Weight Loss Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
LD2	8	0.185662	0.137208	0.07095	0.30037
MSC	1200	0.023399	0.019851	0.02227	0.02452
TC	33	0.036196	0.050693	0.01822	0.05417

Exhibit 6b

Fraction Density Loss By Material (Humidity=0%)



Fraction Density Loss Means and Std Deviations

Level	Number	Mean	Std Dev	Lower 95%	Upper 95%
LD2	8	0.125336	0.082628	0.05626	0.19442
MSC	1190	0.009501	0.010131	0.00892	0.01008
TC	33	0.023993	0.033093	0.01226	0.03573

In addition, only the samples conditioned at humidity 0% were included since they represent 90% of the humidity tests. Plots of weight and density loss by conditioning time are displayed in Exhibits 7a, and 7b, respectively. The data are color coded by conditioning temperature with different character plot points for each sample.

Exhibit 7a

Fraction Weight Loss By Time (days)
Color coded by Temperature (deg F); Markers by Sample ID
MSC Samples; Humidity=0%

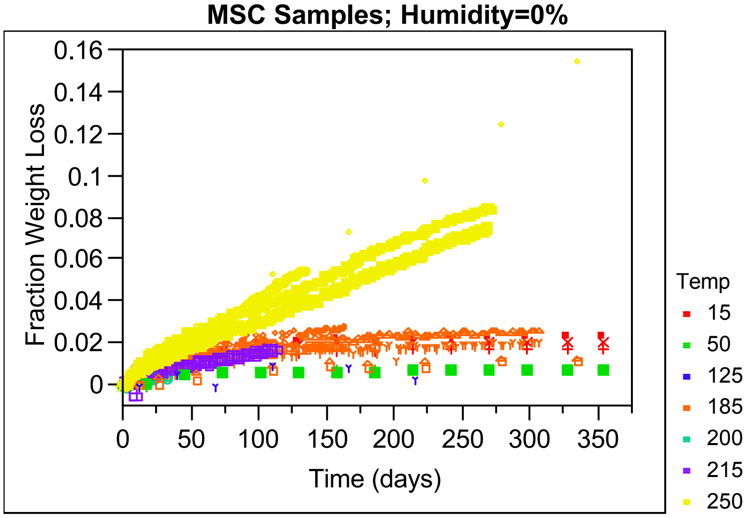
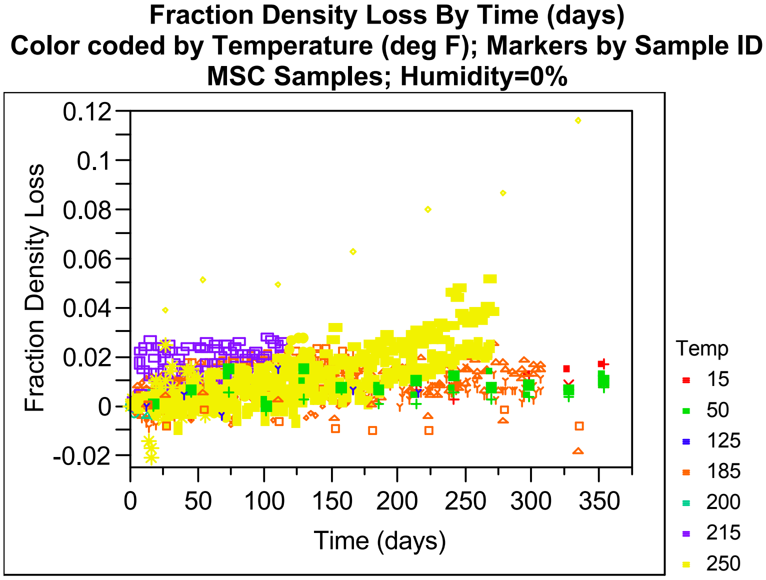


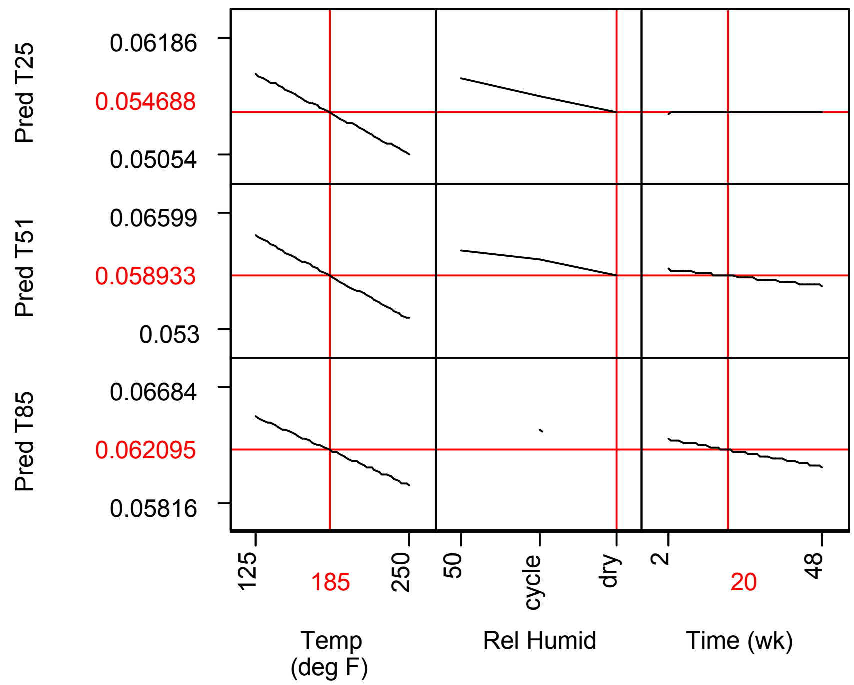
Exhibit 7b



The profile plots are displayed in Plots 3a, 3b, and 3c for conditioning temperature 10, 85 and 121ºC, respectively. The models supporting these plots are displayed in Appendices 6a and 6b for the low conditioning temperature models (Temp≤10ºC) and in Appendices 6c and 6d for the high temperature (Temp ≥85ºC) models. The model for fraction density loss at low temperature does not explain much of the variability of the data (R^2=41%) whereas the model for the fraction weight loss is substantially better for prediction since R^2=82%. The statistical models for high temperature yield an R^2=73% for density loss and 97% for weight loss. There is only a minor impact of conditioning time (days) on mass loss when conditioning temperature is low (10ºC). The impact increases with increasing temperature for both density and weight loss fractions. In particular, the mass loss increases dramatically relative to time (duration) when conditioning temperature is 121ºC. Substantial differences were found among the samples even though the statistical analyses were based on only the MSC material conditioned at 0% humidity. For example, at high temperature (Appendix 6c and 6d), the percentage of variation due to MSC sample differences is 62% for density loss and 93% for weight loss.

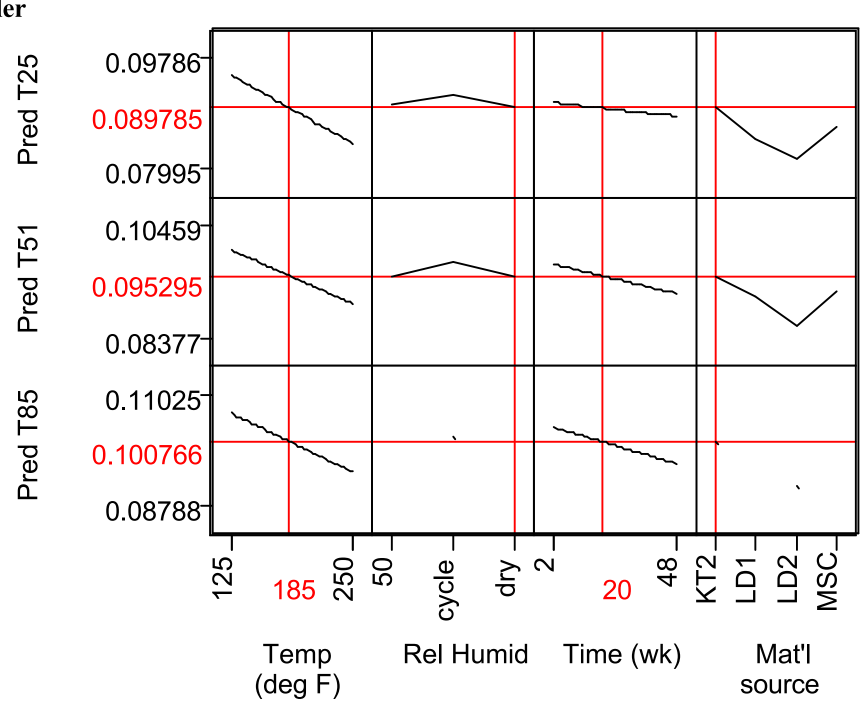
Plot 1a
Thermal Conductivity (W/m-K) at 25, 51 and 85°C using the Axial Orientation

Prediction Profiler



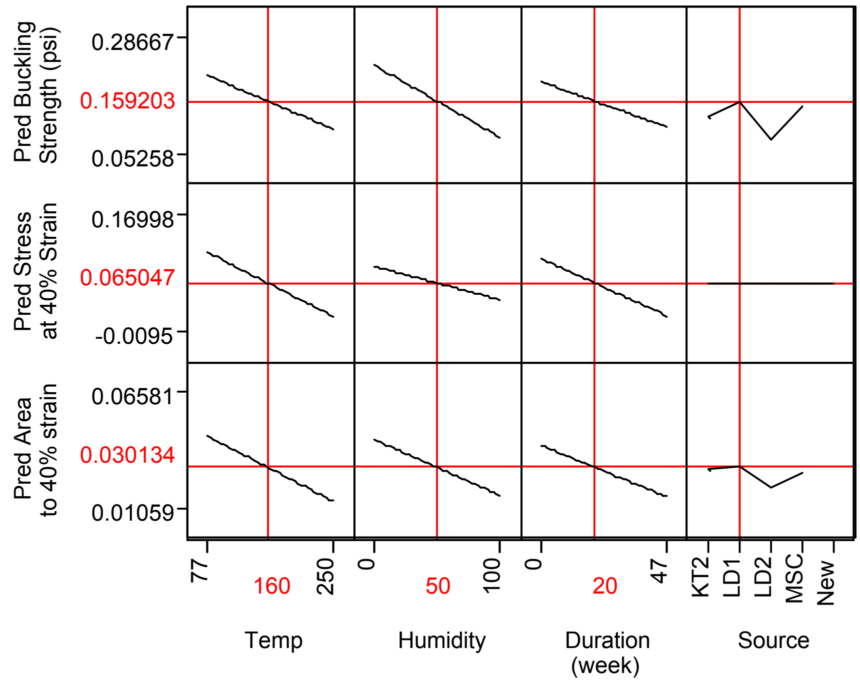
Plot 1b
Thermal Conductivity (W/m-K) at 25, 51 and 85°C using the Radial Orientation

Prediction Profiler



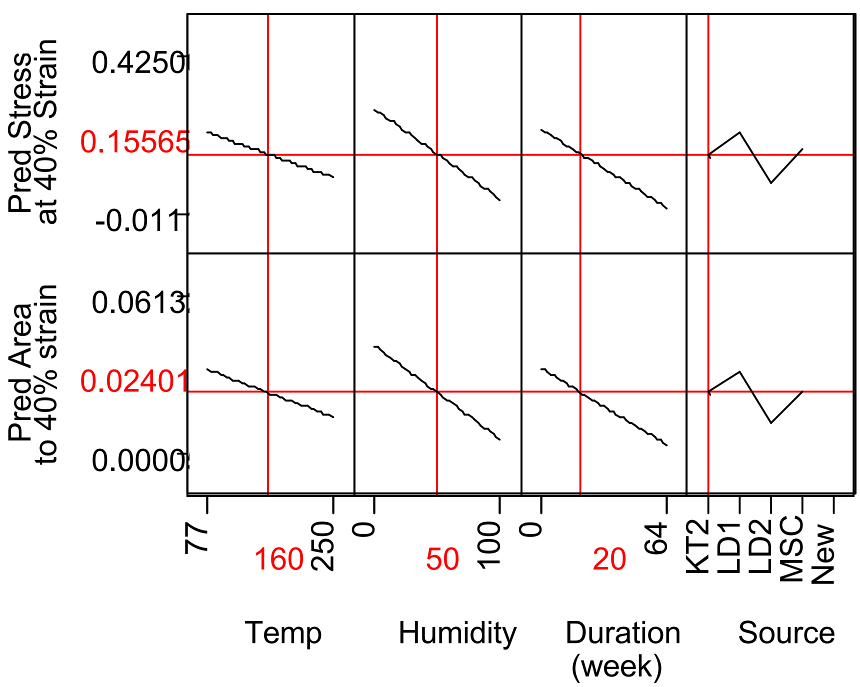
Plot 2a
Compression Results: Parallel Orientation

Prediction Profiler
Temp: degrees F



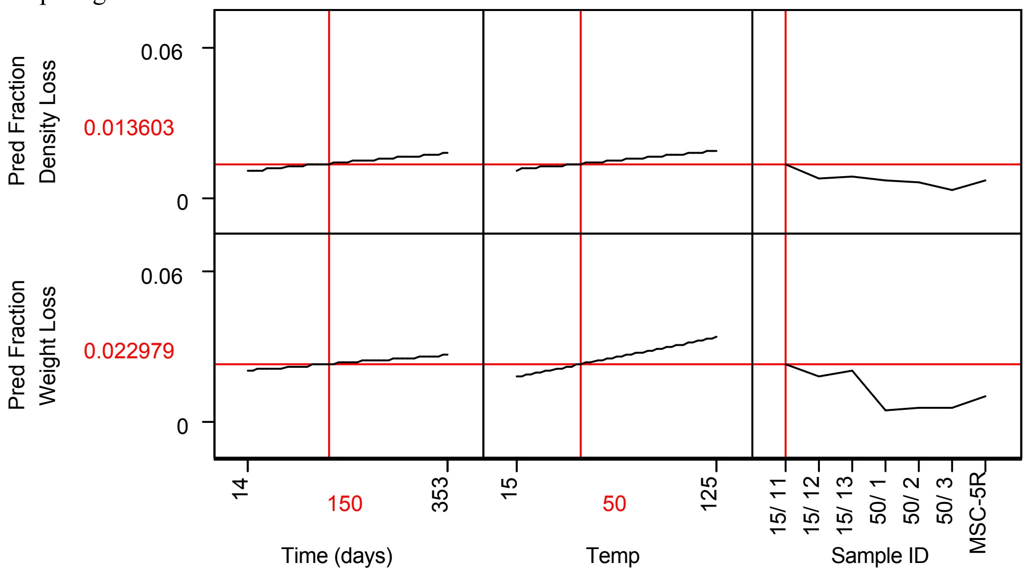
Plot 2b
Compression Results: Perpendicular Orientation

Prediction Profiler
Temp: degrees F



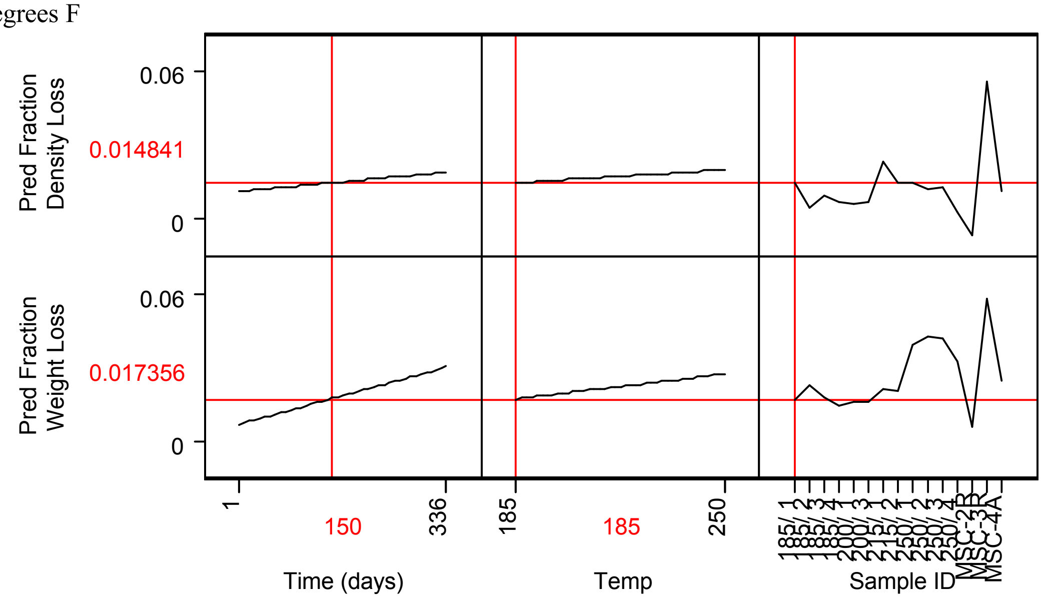
Plot 3a
Mass Loss Results: Prediction at 50°F when Humidity=0%

Prediction Profiler
Temp: degrees F



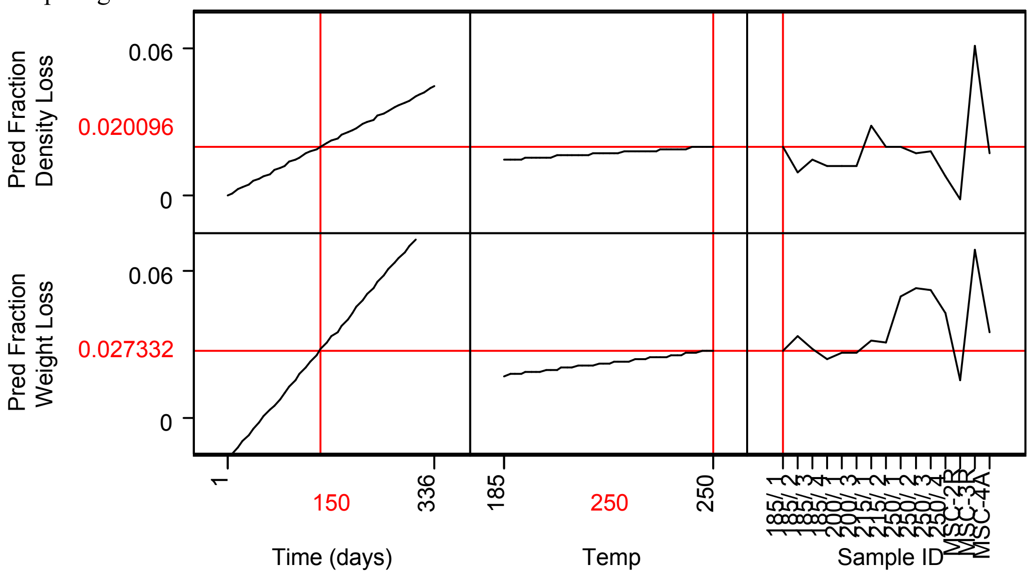
Plot 3b
Mass Loss Results: Prediction at 185°F when Humidity=0%

Prediction Profiler
Temp: degrees F



Plot 3c
Mass Loss: Prediction at 250ºF when Humidity=0%

Prediction Profiler
Temp: degrees F



Path Forward

For the most part, the samples that remain in the several environments will continue to condition and be tested at the previously identified intervals. Changes to the test matrix will be made as follows.

The existing test matrix was designed in part on the assumption that fiberboard from different packages would behave similarly. The data collected to date suggest that variations exist between the different sources. Since each fiberboard assembly is made from precut fiberboard sections of several different configurations, it is also possible that properties vary within a single assembly. This variability was partially addressed in Reference 4 with the addition of compression test samples from a broader range of sources. Statistical analysis indicates that the different source packages provide significant variation in strength and thermal conductivity. Accordingly, additional thermal conductivity samples will be included to further identify the range of variation. These additions are summarized in Table 5.

No significant change has been observed in thermal conductivity samples following conditioning at temperatures of 85ºC and below for up to 48 weeks. Accordingly, thermal conductivity samples conditioning at 51ºC will no longer be tested. Some of these samples will be moved to higher temperature environments. For the present, 2 of the 51ºC samples will remain at that temperature, and will be tested only if data at higher temperatures indicate a change might be occurring. These test matrix changes are summarized in Table 5.

No significant change has been observed to date in any of the specific heat capacity data. Samples will continue to condition in dry ovens at 121 and 85ºC. Samples will also continue to condition at 85ºC 70% relative humidity and 71ºC 50% relative humidity, pending availability of environmental chambers to maintain these environments. After additional time is accumulated for these humid environments (up to ~48 weeks) they may then be discontinued if no change has yet occurred. The samples at 121ºC will continue to be tested at 8 week intervals. The test interval for the other samples will be increased to 16 weeks.

Significant change in weight and density is seen in the mass loss samples conditioned at higher temperatures. These samples are all from a single source (MSC). In order to define the range of variability in these physical properties, additional mass loss samples will be prepared from as many sources as are currently available. They will be conditioned in the following environments: 71ºC 50% relative humidity, 85ºC dry, 85ºC 70% relative humidity, 102ºC dry, and 121ºC dry. To minimize the effort involved, the frequency for measuring mass loss samples will be changed from daily to weekly.

Conclusions

Statistical analysis of the data to date indicates several relevant trends. With the accumulation of additional data, they should permit extrapolation to KAMS conditions to allow prediction of service life (pending identification of acceptance criteria for each property). Several trends and observations are suggested by the data at this time. Specifically:

- The various properties (thermal conductivity, specific heat capacity, compression strength, weight, density) vary at different rates within a given environment. For example, at 121ºC, specific heat capacity and axial thermal conductivity show little change after ~1 year, the compression strength experiences a noticeable decrease around 16 weeks, and the radial thermal conductivity, weight and density show continual steady decrease over the entire period.
- Where observed, the degradation to date varies both with temperature and humidity. Little change is seen in any measured property at temperatures of 51ºC and below. Changes are generally greater with elevated humidity levels than in dry environments.
- At elevated temperatures, fiberboard weight generally decreases faster than density. This indicates that dimensions are decreasing along with weight, to reduce the effect of weight loss on density. Limits have been established [6] for fiberboard density and certain dimensions on the basis of maintaining the criticality control function.
- The specific heat capacity has not changed significantly in aging studies to date. The total heat capacity of the package is derived from both specific heat capacity and fiberboard weight. Fiberboard weight has shown changes over time in the current data.

References

[1] WSRC-TR-2003-00325, Rev. 2, "Task Technical and Quality Assurance Plan for Characterization and Surveillance of Model 9975 Package O-Rings and Celotex® Materials", K. A. Dunn, February 2005

[2] WSRC-TR-2004-00523, "Baseline Mechanical Property Data for Model 9975 Package Celotex® Material", W. L. Daugherty, December 2004

[3] WSRC-TR-2004-00481, "Thermal Conductivity and Specific Heat Capacity Testing on 9975 Package Cane Fiberboard", P. R. Vormelker, December 2004

[4] SRNL-MTS-2006-00006, "Long-Term Plan for Fiberboard Testing", W. L. Daugherty, January 30, 2006

[5] Laboratory Notebooks WSRC-NB-2005-00034 "9975 Shipping Package Celotex Testing" and WSRC-NB-2006-00060 "9975 Shipping Package Celotex Testing"

[6] WSMS-CRT-03-0158, "9975 Surveillance Program – Assessment of Celotex® Properties", D. Biswas, December 16, 2003

Table 1. Matrix for fiberboard conditioning and testing through 16 weeks

Environment	2 wk	4 wk	6 wk	8 wk	10 wk	12 wk	14 wk	16 wk
Compression test, parallel orientation								
25°C, 70% RH	AB			AB				
51°C, dry	ABC**BC**	ABC		ABC**BC**				AB**BC**
51°C, 70% RH	ABC	ABC		ABC				AB
51°C, dry / 70% RH cycle			AB	AB	AB	AB		AB
51 °/ 85C cycle, 70% RH		AB		AB			AB	AB
71°C, 50% RH	AABCCD	AAD		AABCCDD				
85°C, dry	ABC**F**	ABC		ABC				AB
85°C, 70% RH	ABC	ABC		ABC		**AB**		
85°C, dry / 70% RH cycle			AB	AB	AB		AB	AB
102°C, dry	**AABCC**			**ABC**				**AABCC**
121°C, dry	AA**CF**	A		AB**CFF**				AB
Compression test, perpendicular orientation								
25°C, 70% RH	AB			A				
51°C, dry	ABC			AA				AA
51°C, 70% RH	ABC			AA				A
51°C, dry / 70% RH cycle			AB	AB		AB		AB
51 / 85°C cycle, 70% RH							AB	AB
71°C, 50% RH	AABCCD			AAD				
85°C, dry	ABC**F**			AA				AA
85°C, 70% RH	ABC			AA				
85°C, dry / 70% RH cycle			AB	AB			AB	AB
102°C, dry	**ABC**							**ABC**
121°C, dry	AA**CF**			AA**CF**				AA
Thermal conductivity test								
51°C, dry	**C**		**C**		**C**			**C**
51°C, dry / 70% RH cycle			CCCA	CCCA		CCCA		CCCA
71°C, 50% RH	AEBC			AEBC				
85°C, dry	CCCC	CCCC		CCCC				CCCC
85°C, dry / 70% RH cycle			CCCB		CCCB		CCCB	CCCB
102°C, dry				**CEE**				**CEE**
121°C, dry	BCCC	BCCC		BCCC				BCCC
Specific heat capacity test								
51°C, dry	**CC**		**CC**		**CC**			**CC**
51°C, dry / 70% RH cycle	**CC**		CCC		CCC	CCCC		CCC
71°C, 50% RH		CCCC		CCCC				
85°C, dry	CCC	CCC		CCC				CCC
85°C, dry / 70% RH cycle			CCC		CCC		CCC	CCCC
121°C, dry	CCC	CCC		CCCC				CCC

Material source: A = LD1 (lower assembly, dropped package 1), B = LD2 (lower assembly, dropped package 2), C = MSC (miscellaneous), D = KAMS-TEST-2, E = KAMS surveillance package (9975-02234 or 9975-00826), F = New assembly

Samples in **Bold** are in addition to the test matrix described in the task technical plan.

Table 2. Matrix for fiberboard conditioning and testing beyond 16 weeks

Environment	32 wk	47 wk	64 wk	96 wk
Compression test, parallel orientation				
51°C, dry	**BC**		BC	tbd
51°C, 70% RH moved to dry	AB		AB	tbd
51°C, cycle RH moved to dry	**C**		CC	tbd
71°C, 50% RH	tbd		tbd	tbd
85°C, dry	**ABC** FF		ABC	AB
85°C, 70% RH	tbd		tbd	tbd
85°C, cycle RH moved to dry	**C**		C	tbd
102°C, dry	ABC		AABC	tbd
121°C, dry	**BC** FF	**C**	**BC**	tbd
Compression test, perpendicular orientation				
51°C, dry	**C**		C	tbd
51°C, 70% RH moved to dry	AB		AB	tbd
51°C, cycle RH moved to dry	**C**		C	tbd
71°C, 50% RH	tbd		tbd	tbd
85°C, dry	**C**		ABC	AB
85°C, 70% RH	tbd		tbd	tbd
85°C, cycle RH moved to dry	**C**		C	tbd
102°C, dry	ABC		AABC	tbd
121°C, dry	**BC**	**C**	**BC**	tbd

	24 wk	32 wk	40 wk	48 wk	Continuing 8 wk intervals
Thermal conductivity					
51°C, dry	**C**	**C**	**C**	**C**	C
51°C, cycle RH moved to dry	**CCCA**	**CCCA**	**CCCA**	**CCCA**	CCCA
71°C, 50% RH	tbd	tbd	tbd	tbd	tbd
85°C, dry	**CCCC**	**CCCC**	**CCCC**	**CCCC**	CCCC
85°C, cycle RH moved to dry	**CCCB**	**CCCB**	**CCCB**	**CCCB**	CCCB
102°C, dry	CEE	CEE	CEE	CEE	CEE
121°C, dry	**BCCC**	**BCCC**	**BCCC**	**BCCC**	BCCC
Specific heat capacity					
51°C, dry	**CC**	**CC**	**CC**	CC	CC
51°C, cycle RH moved to dry	**CCCC**	**CCCCC**	**CCCCC**	**CCCCC**	CCCCC
71°C, 50% RH	tbd	tbd	tbd	tbd	tbd
85°C, dry	**CCCCC**	**CCCCC**	**CCCCC**	**CCCCC**	CCCCC
85°C, cycle RH moved to dry	**CCC**	**CCCCC**	**CCCCC**	**CCCCC**	CCCCC
121°C, dry	**CCCCC**	**CCCCC**	**CCCCC**	**CCCCC**	CCCCC

Material source: A = LD1 (lower assembly, dropped package 1), B = LD2 (lower assembly, dropped package 2), C = MSC (miscellaneous), D = KAMS-TEST-2, E = KAMS surveillance package (9975-02234 or 9975-00826), F = New assembly

Samples in **Bold** have been tested as of 7 August 2006.

Table 3. Comparative numerical data from compression test samples – parallel orientation

Material Source	Duration (week)	Buckling Strength (ksi)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)	Material Source	Duration (week)	Buckling Strength (ksi)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)
25°C, 70% relative humidity									
LD1	2	0.214	0.04633	0.125	LD1	8	0.193	0.04188	0.115
LD2	2	0.156	0.04194	0.149	LD2	8	0.129	0.03666	0.115
51°C, 70% relative humidity									
LD1	2	0.173	0.0438	0.147	LD1	8	0.183	0.0373	0.104
LD2	2	0.136	0.02826	0.08	LD2	8	0.136	0.03715	0.088
MSC	2	0.184	0.04165	0.104	MSC	8	0.17	0.03799	0.076
LD1	4	0.178	0.03727	0.12	LD1	16	0.175	0.04532	0.138
LD2	4	0.136	0.03705	0.126	LD2	16	0.102	0.02547	0.071
MSC	4	0.186	0.04355	0.135					
51°C, dry									
LD1	2	0.242	0.04619	0.098	LD1	8	0.202	0.03589	0.044
LD2	2	0.152	0.03783	0.073	LD2	8	0.189	0.04493	0.133
LD2	2	0.173	0.04269	0.104	MSC	8	0.27	0.05829	0.132
MSC	2	0.246	0.04097	0.075	LD1	16	0.258	0.04036	0.147
MSC	2	0.248	0.04724	0.128	LD2	16	0.206	0.04157	0.091
LD1	4	0.289	0.05578	0.153	LD2	16	0.172	0.03629	0.08
LD2	4	0.158	0.04596	0.113	MSC	16	0.279	0.0404	0.051
MSC	4	0.264	0.0568	0.098	LD2	32	0.16	0.04179	0.091
LD2	7	0.208	0.04345	0.105	MSC	32	0.257	0.03476	0.021
MSC	7	0.234	0.03736	0.111					
71°C, 50% relative humidity									
LD1	2	0.243	0.05709	0.189	KT2	4	0.24	0.04327	0.081
LD1	2	0.218	0.05243	0.135	KT2	8	0.198	0.05973	0.185
LD2	2	0.126	0.03175	0.104	KT2	8	0.215	0.04247	0.135
MSC	2	0.203	0.03652	0.079	MSC	8	0.201	0.04657	0.134
MSC	2	0.22	0.04104	0.089	LD1	8	0.184	0.05653	0.181
KT2	2	0.148	0.02479	0.034	LD1	8	0.216	0.05192	0.156
LD1	4	0.181	0.03344	0.084	LD2	8	0.113	0.03654	0.141
LD1	4	0.257	0.0506	0.08	MSC	8	0.231	0.06255	0.218
85°C, 70% relative humidity									
LD1	2	0.187	0.04988	0.136	MSC	4	0.159	0.02422	0.05
LD2	2	0.123	0.02756	0.069	LD1	8	0.124	0.01809	0.036
MSC	2	0.182	0.04331	0.099	LD2	8	0.112	0.02476	0.07
LD1	4	0.15	0.0367	0.066	MSC	8	0.13	0.02532	0.031
LD2	4	0.053	0.01802	0.062					
85°C, dry									
LD1	2	0.196	0.03527	0.058	LD2	8	0.155	0.03662	0.075
LD2	2	0.17	0.03488	0.08	MSC	8	0.196	0.0374	0.071
MSC	2	0.187	0.03318	0.042	LD1	16	0.206	0.04565	0.096
New	2	0.308	0.04696	0.09	LD2	16	0.089	0.02506	0.057
LD1	4	0.24	0.0311	0.049	LD1	32	0.227	0.03117	0.046
LD2	4	0.196	0.04593	0.103	LD2	32	0.08	0.019	0.051
MSC	4	0.148	0.02479	0.034	MSC	32	0.222	0.04575	0.096
LD1	8	0.212	0.03798	0.078					

Table 3. Comparative numerical data from compression test samples – parallel orientation (continued)

Material Source	Duration (week)	Buckling Strength (ksi)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)	Material Source	Duration (week)	Buckling Strength (ksi)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)
		102^{o}C, dry							
LD1	2	0.222	0.04928	0.046	MSC	8	0.2	0.01881	0.018
LD1	2	0.306	0.04161	0.169	LD1	16	0.209	0.04175	0.091
LD2	2	0.147	0.02582	0.044	LD1	16	0.255	0.03421	0.034
MSC	2	0.223	0.03976	0.086	LD2	16	0.153	0.02797	0.077
MSC	2	0.207	0.03536	0.074	MSC	16	0.201	0.0264	0.054
LD1	8	0.296	0.03354	0.083	MSC	16	0.206	0.03739	0.084
LD2	8	0.115	0.02865	0.065					
		121^{o}C, dry							
LD1	2	0.214	0.0399	0.076	New	8	0.255	0.04001	0.123
LD1	2	0.187	0.05071	0.145	New	8	0.257	0.03561	0.093
MSC	2	0.212	0.04724	0.107	LD1	16	0.109	0.01127	0
New	2	0.288	0.05224	0.103	LD2	16	0.121	0.0178	0.034
LD1	4	0.173	0.02733	0.03	LD2	32	0.095	0.01589	0.046
MSC	7	0.222	0.04097	0.095	MSC	32	0.094	0.01575	0.032
LD1	8	0.125	0.01124	0.015	MSC	47	0.058	0.00686	0.01
LD2	8	0.132	0.01987	0.018	MSC	64	0.049	0.0917	0.012

Table 4. Comparative numerical data from compression test samples – perpendicular orientation

Material Source	Duration (week)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)	Material Source	Duration (week)	Energy to 40% strain (%-ksi)	Stress at 40% Strain (ksi)
25°C, 70% relative humidity							
LD1	2	0.04199	0.291	LD1	8	0.03809	0.264
LD2	2	0.02634	0.178				
51°C, 70% relative humidity							
LD1	2	0.03932	0.282	LD1	8	0.0323	0.227
LD2	2	0.02157	0.144	LD1	8	0.03631	0.251
MSC	2	0.02787	0.168	LD1	16	0.03494	0.246
51°C, dry							
LD1	2	0.05754	0.41	LD1	8	0.05571	0.402
LD2	2	0.02523	0.186	LD1	16	0.05824	0.418
MSC	2	0.05386	0.374	LD1	16	0.05647	0.402
LD1	8	0.05589	0.394	MSC	32	0.05541	0.388
71°C, 50% relative humidity							
LD1	2	0.04457	0.307	KT2	2	0.04537	0.322
LD1	2	0.04925	0.326	KT2	8	0.04853	0.338
LD2	2	0.3033	0.202	LD1	8	0.04093	0.253
MSC	2	0.04718	0.325	LD1	8	0.03585	0.233
MSC	2	0.03317	0.199				
85°C, dry							
LD1	2	0.04797	0.344	LD1	8	0.05364	0.379
LD2	2	0.03247	0.21	LD1	16	0.04714	0.343
MSC	2	0.03721	0.227	LD1	16	0.04286	0.283
New	2	0.06896	0.461	MSC	32	0.04012	0.243
LD1	8	0.05547	0.39				
85°C, 70% relative humidity							
LD1	2	0.03622	0.263	LD1	8	0.0355	0.247
LD2	2	0.267	0.172	LD1	8	0.03444	0.24
MSC	2	0.277	0.167				
102°C, dry							
LD1	2	0.05361	0.348	LD1	16	0.05303	0.355
LD2	2	0.0333	0.21	LD2	16	0.03106	0.195
MSC	2	0.03293	0.302	MSC	16	0.03189	0.267
121°C, dry							
LD1	2	0.04878	0.338	New	8	0.05382	0.36
LD1	2	0.04593	0.321	LD1	16	0.02646	0.167
MSC	2	0.05215	0.355	LD1	16	0.02171	0.143
New	2	0.06495	0.435	LD2	32	0.02348	0.149
MSC	7	0.05202	0.0362	MSC	32	0.02053	0.124
LD1	8	0.04258	0.297	MSC	47	0.01232	0.079
LD1	8	0.04453	0.318	MSC	64	0.01232	0.079

Table 5. Recommended changes in test matrix for thermal conductivity samples

	Current sample matrix *		Proposed sample matrix **		
Thermal conductivity	Axial	Radial	Axial	Radial	Comments
51°C, dry		C		(C)	
51°C, cycle RH	CC	AC		(C)	Move samples to other environments as noted
71°C, 50% RH	AE	BC	ACEF	BCEF	C axial sample from 51°C cycle
85°C, dry	CC	CC	CF(C)	CF(C)	
85°C, cycle RH	CC	BC	BCF(C)	BCF	Humidity to remain at 70%
102°C, dry	E	CE	BCEF	BCEF	C axial sample from 51°C cycle
121°C, dry	BC	CC	BCEF	ACEF(C)	A radial sample from 51°C cycle

* Material source: A = LD1 (lower assembly, dropped package 1), B = LD2 (lower assembly, dropped package 2), C = MSC (miscellaneous), E = KAMS surveillance package (9975-02234 or 9975-00826), F = New assembly

** Samples in parentheses will continue conditioning in the environment, but will not be tested unless data from other samples indicates a need for further data.

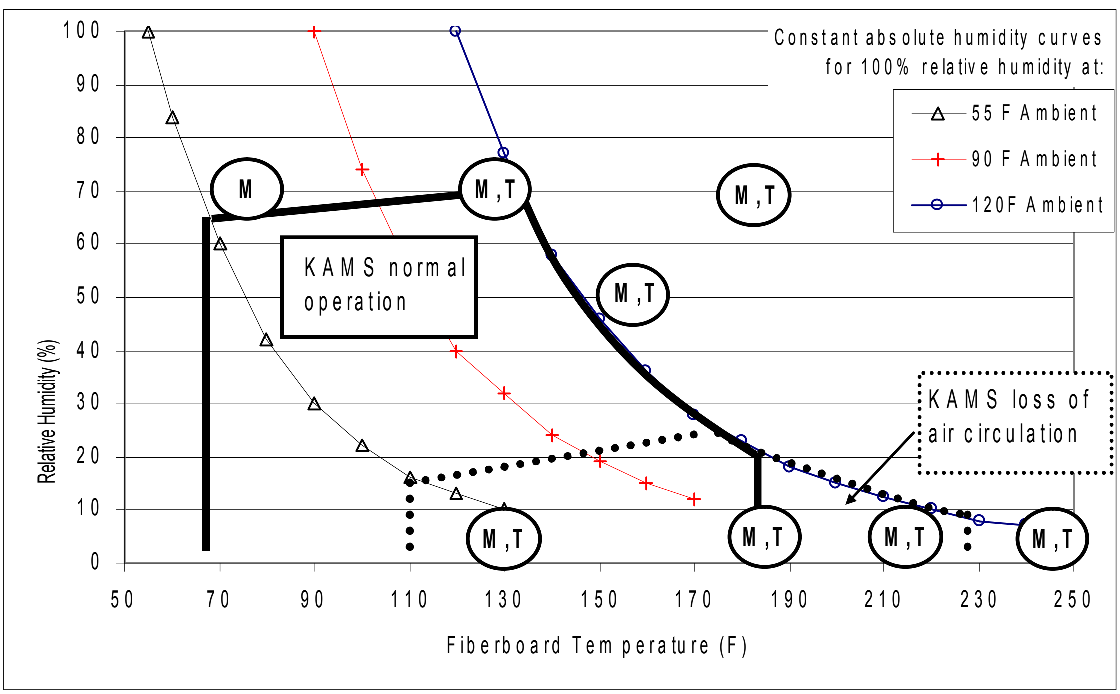
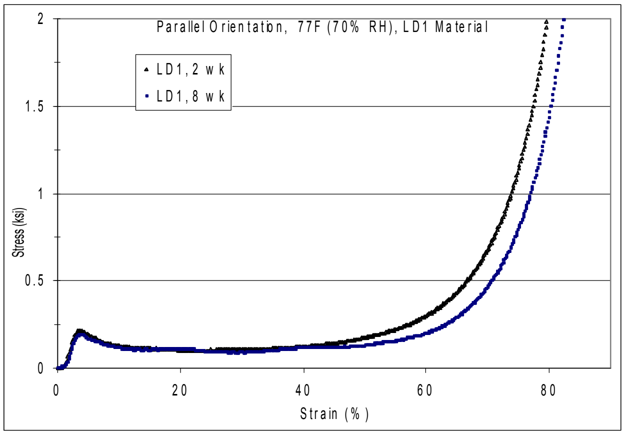
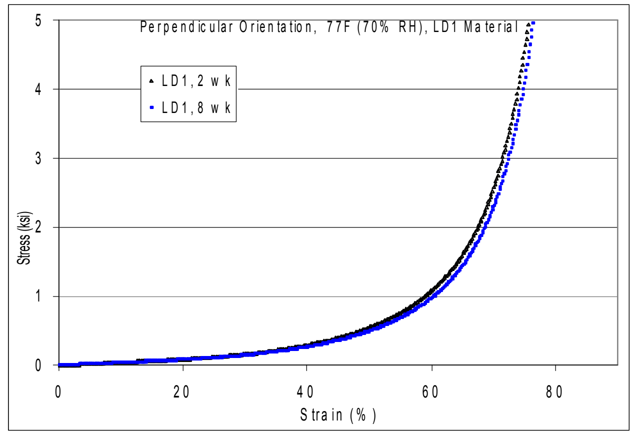


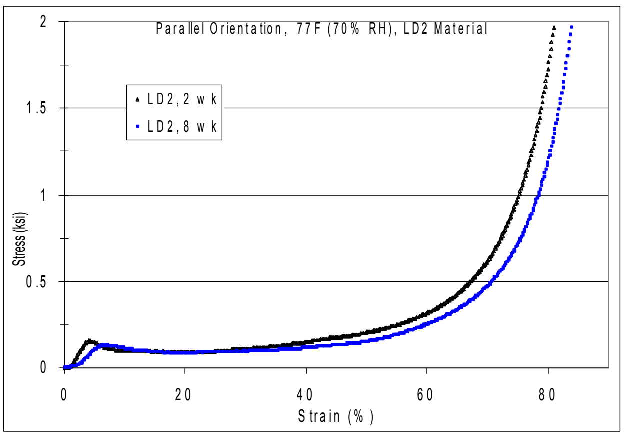
Figure 1. Range of environments which Celotex® in KAMS can experience under normal operation and under loss of air circulation (both ventilation and natural convection). Also shown are the environments for longer-term aging and testing (circles). "M" denotes mechanical testing. "T" denotes thermal testing.



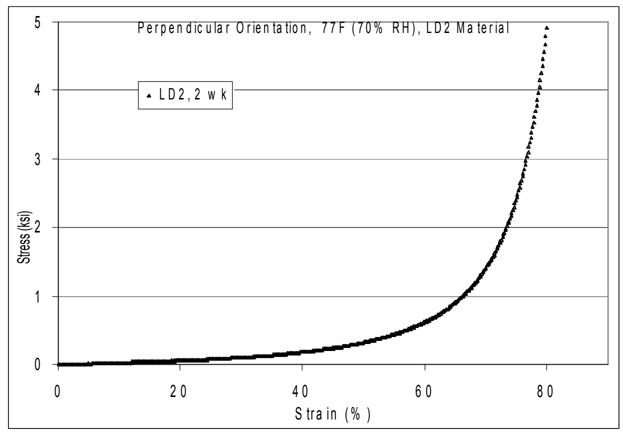
(a)



(b)

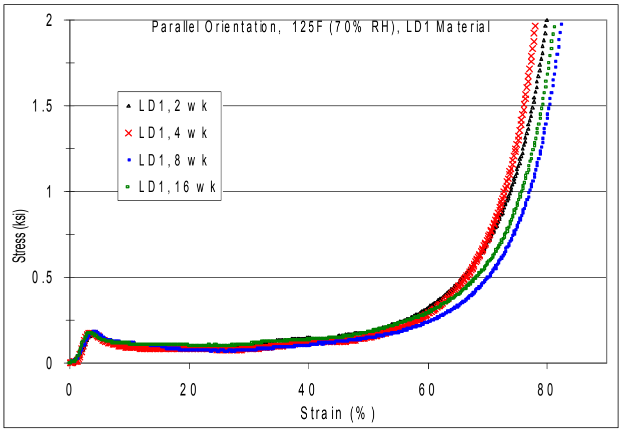


(c)

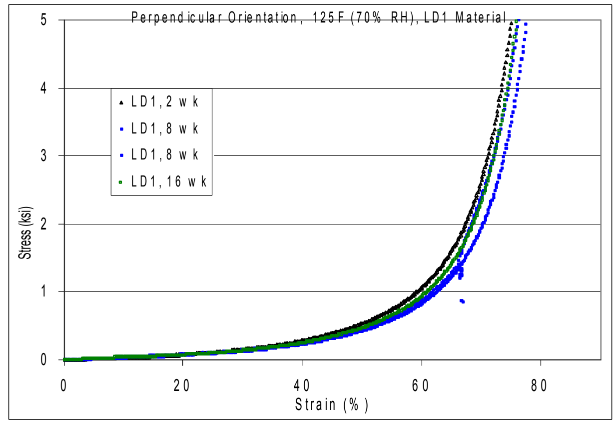


(d)

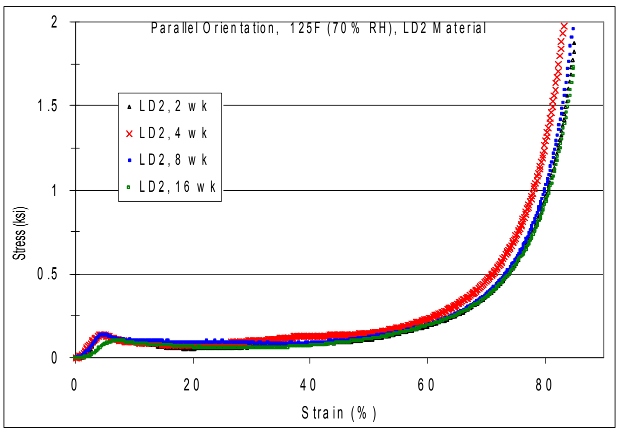
Figure 2. Engineering stress-strain compression curves for fiberboard samples conditioned at 25ºC (77ºF), 70% relative humidity.



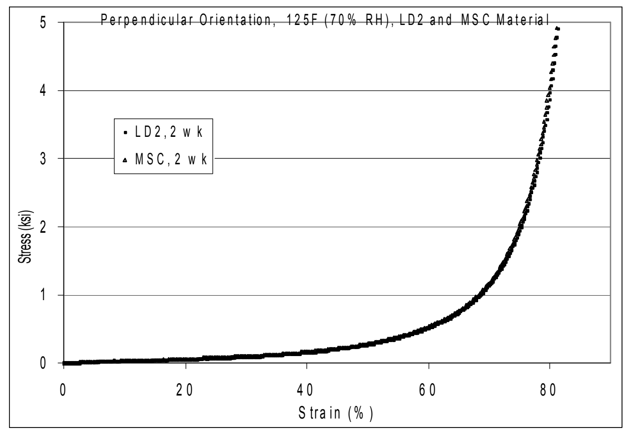
(a)



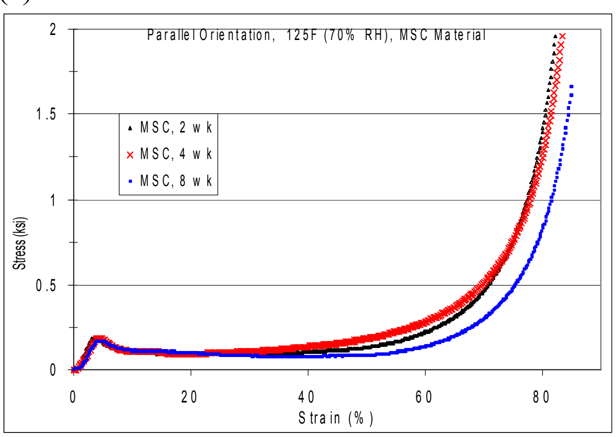
(b)



(c)

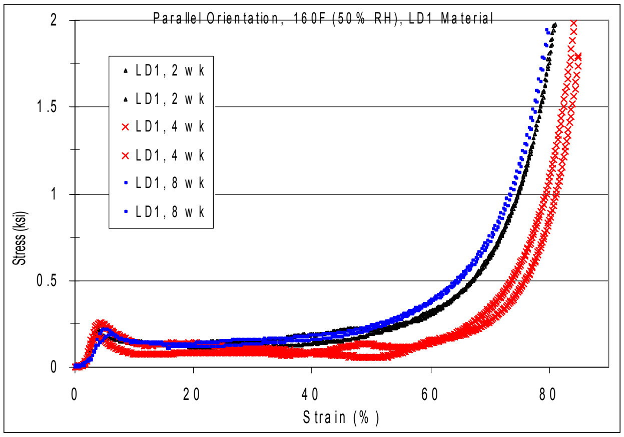


(d)

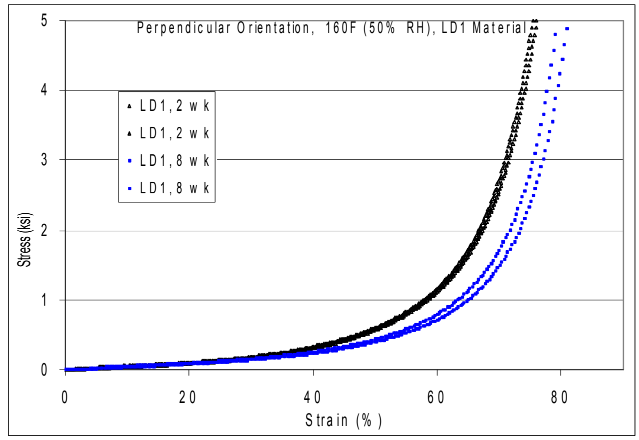


(e)

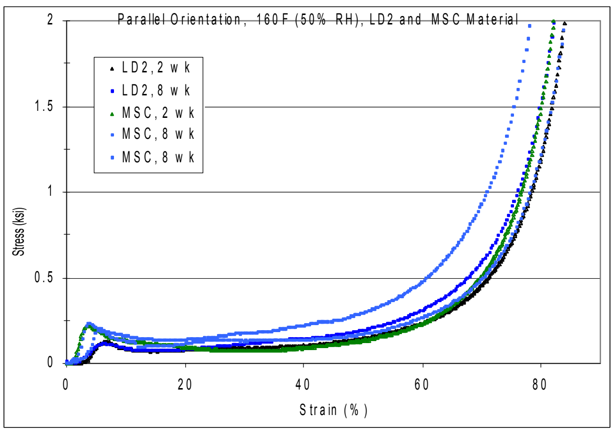
Figure 3. Engineering stress-strain compression curves for fiberboard samples conditioned at 51ºC (125ºF), 70% relative humidity.



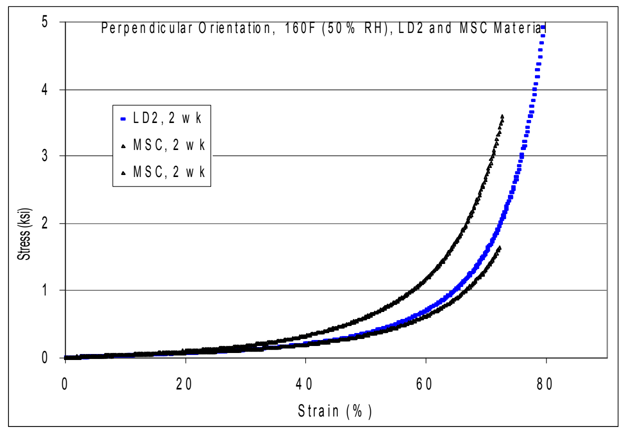
(a)



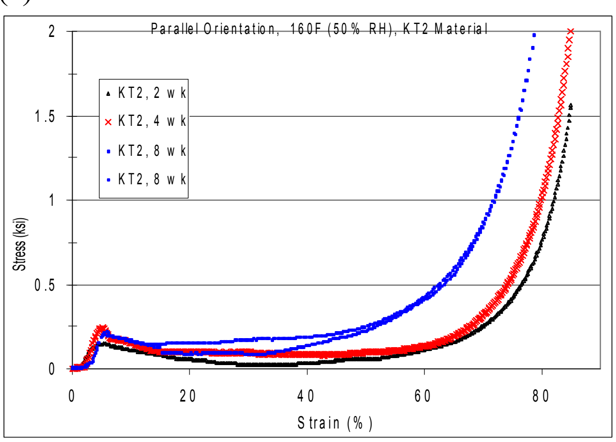
(b)



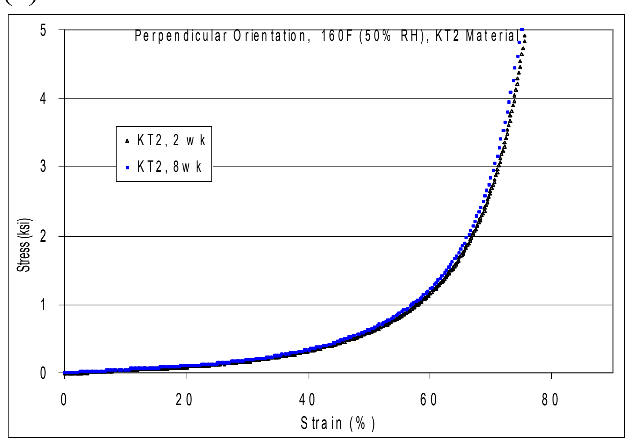
(c)



(d)

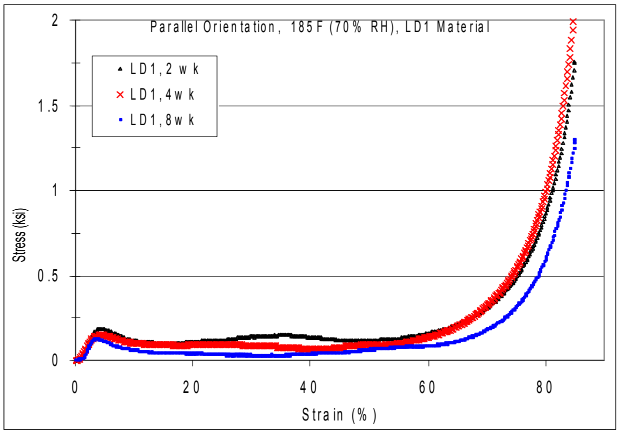


(e)

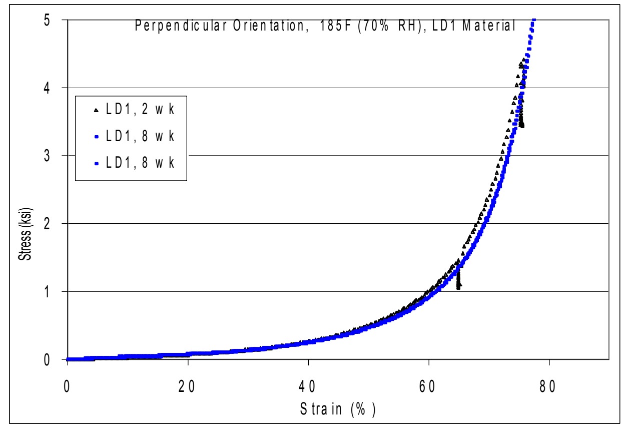


(f)

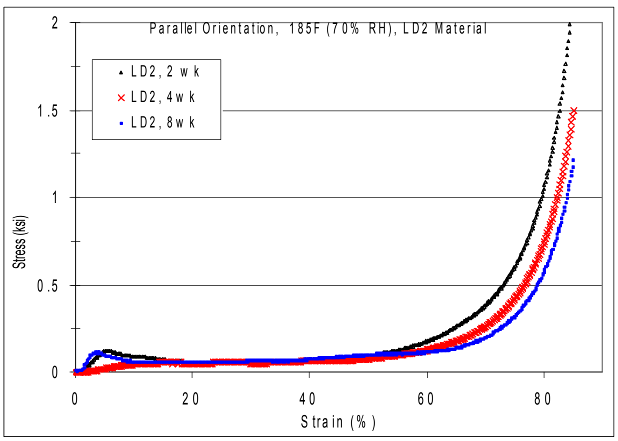
Figure 4. Engineering stress-strain compression curves for fiberboard samples conditioned at 71ºC (160ºF), 50% relative humidity.



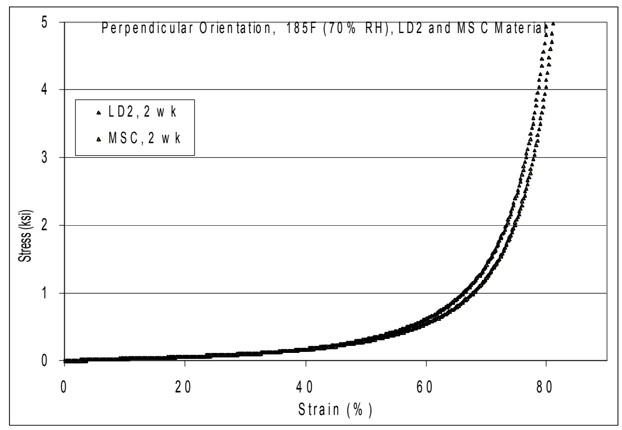
(a)



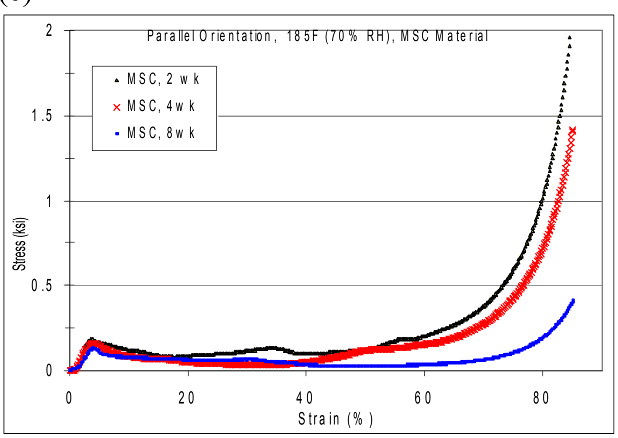
(b)



(c)

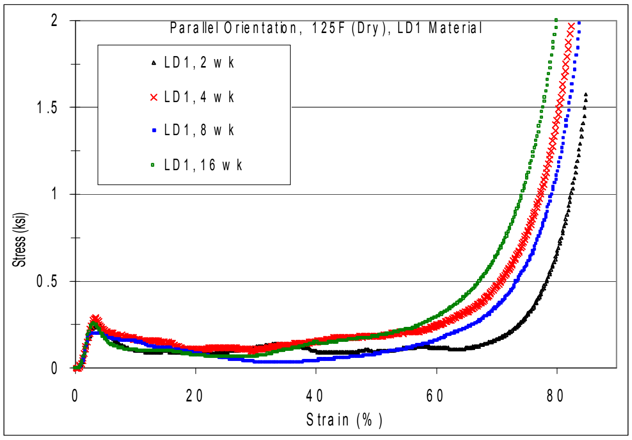


(d)

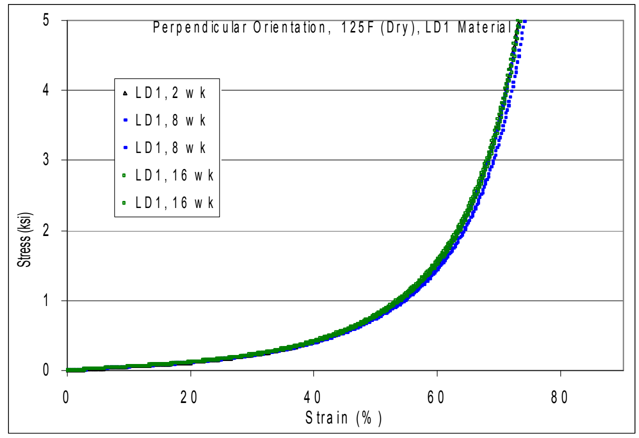


(e)

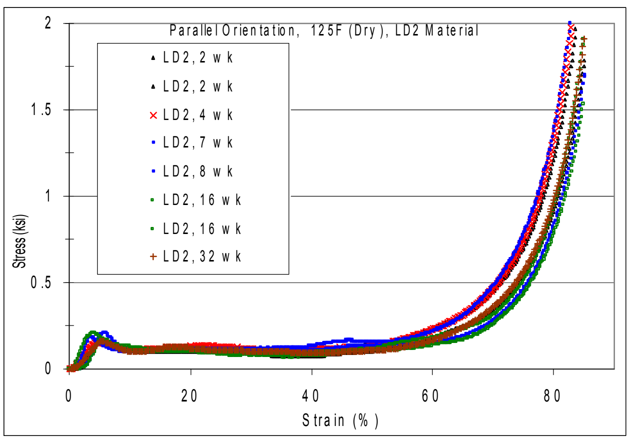
Figure 5. Engineering stress-strain compression curves for fiberboard samples conditioned at 85ºC (185ºF), 70% relative humidity.



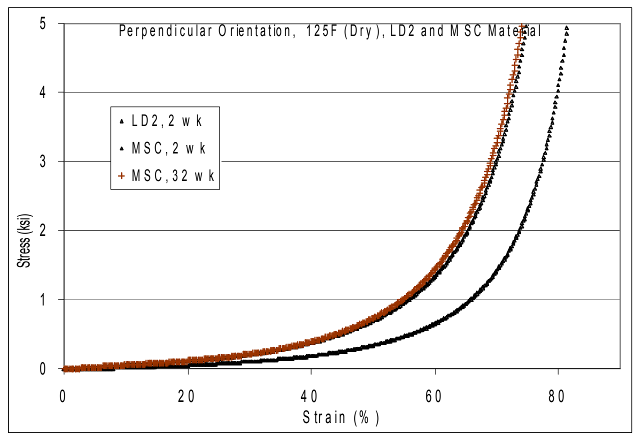
(a)



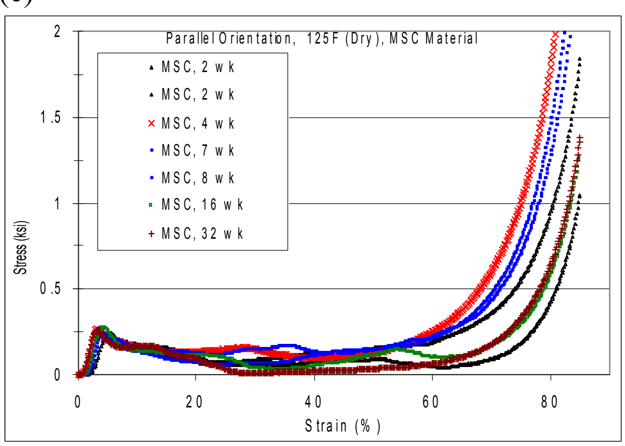
(b)



(c)

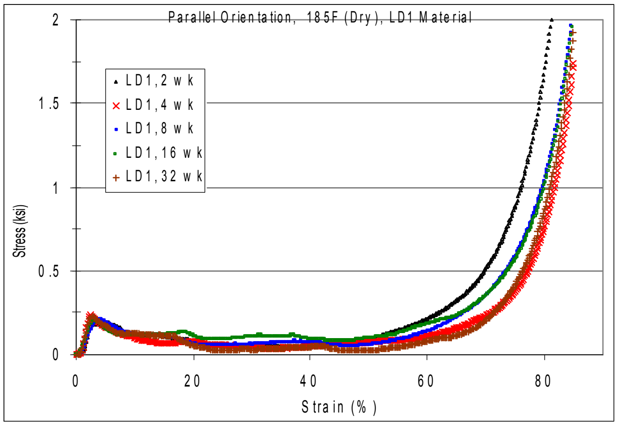


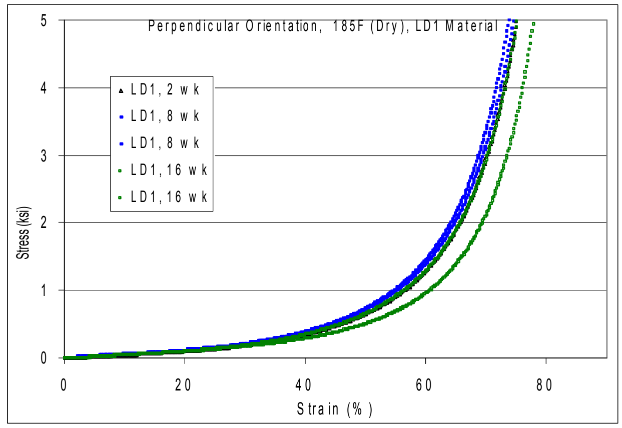
(d)



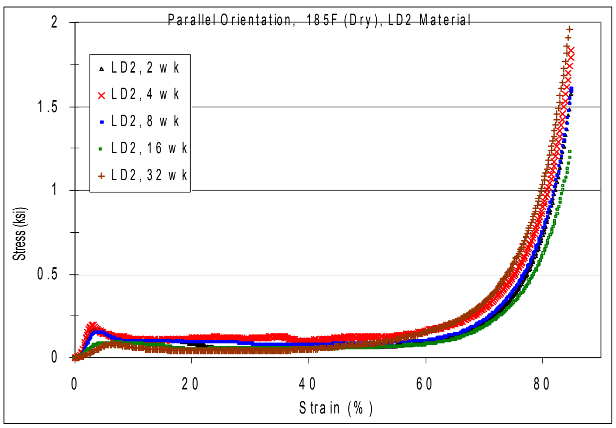
(e)

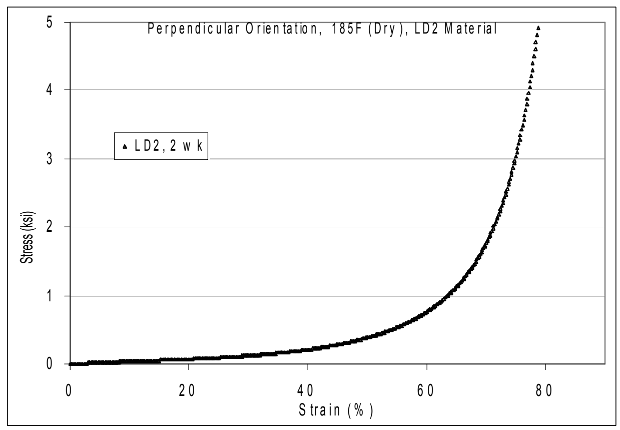
Figure 6. Engineering stress-strain compression curves for fiberboard samples conditioned at 51ºC (125ºF), dry oven.



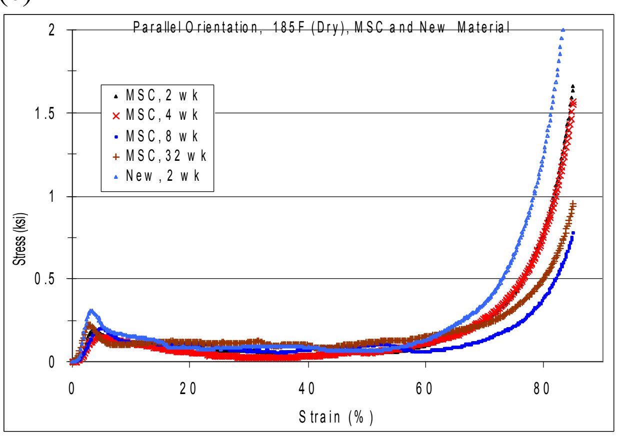


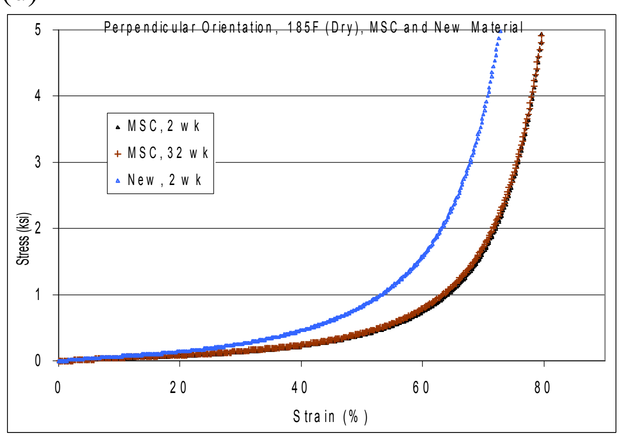
(a) (b)





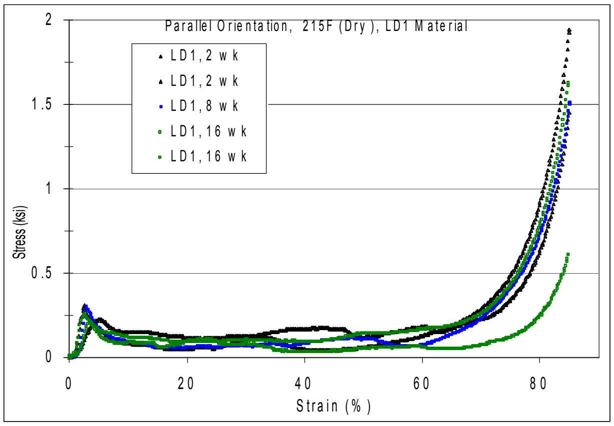
(c) (d)



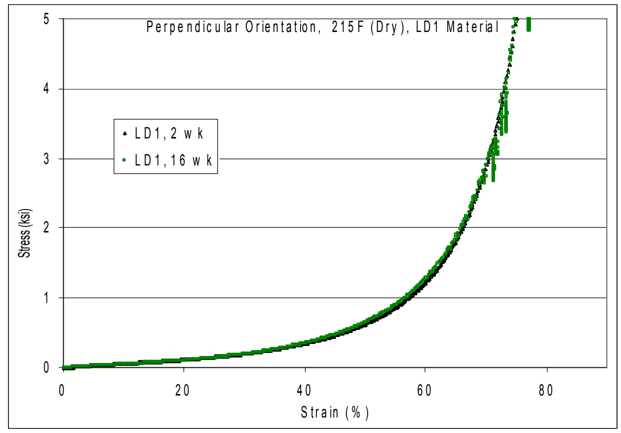


(e) (f)

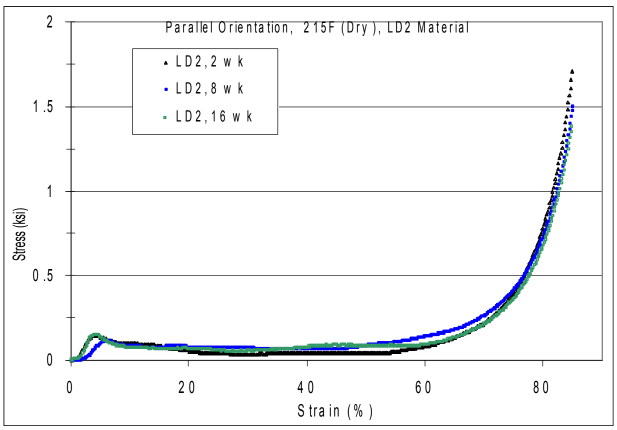
Figure 7. Engineering stress-strain compression curves for fiberboard samples conditioned at 85ºC (185ºF), dry oven.



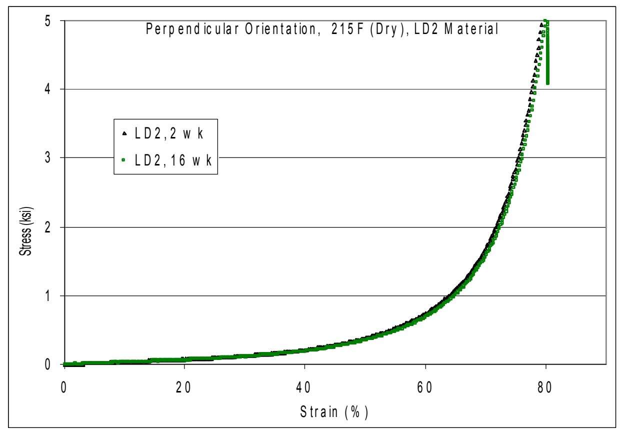
(a)



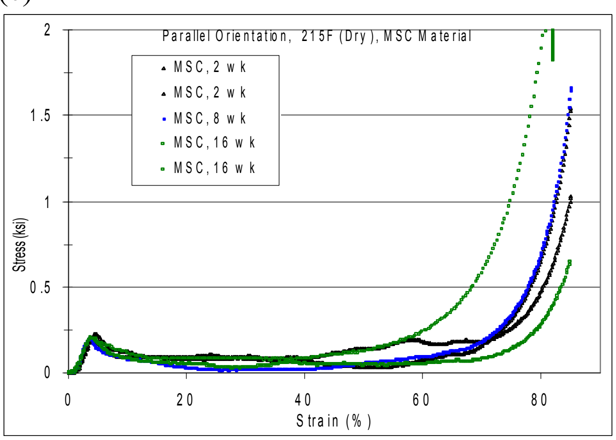
(b)



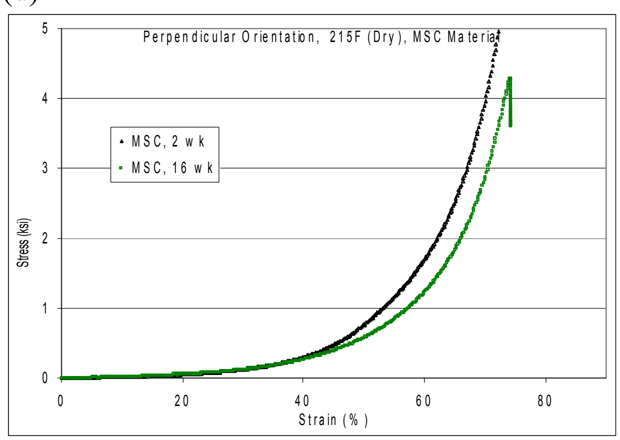
(c)



(d)



(e)



(f)

Figure 8. Engineering stress-strain compression curves for fiberboard samples conditioned at 102ºC (215ºF), dry oven.

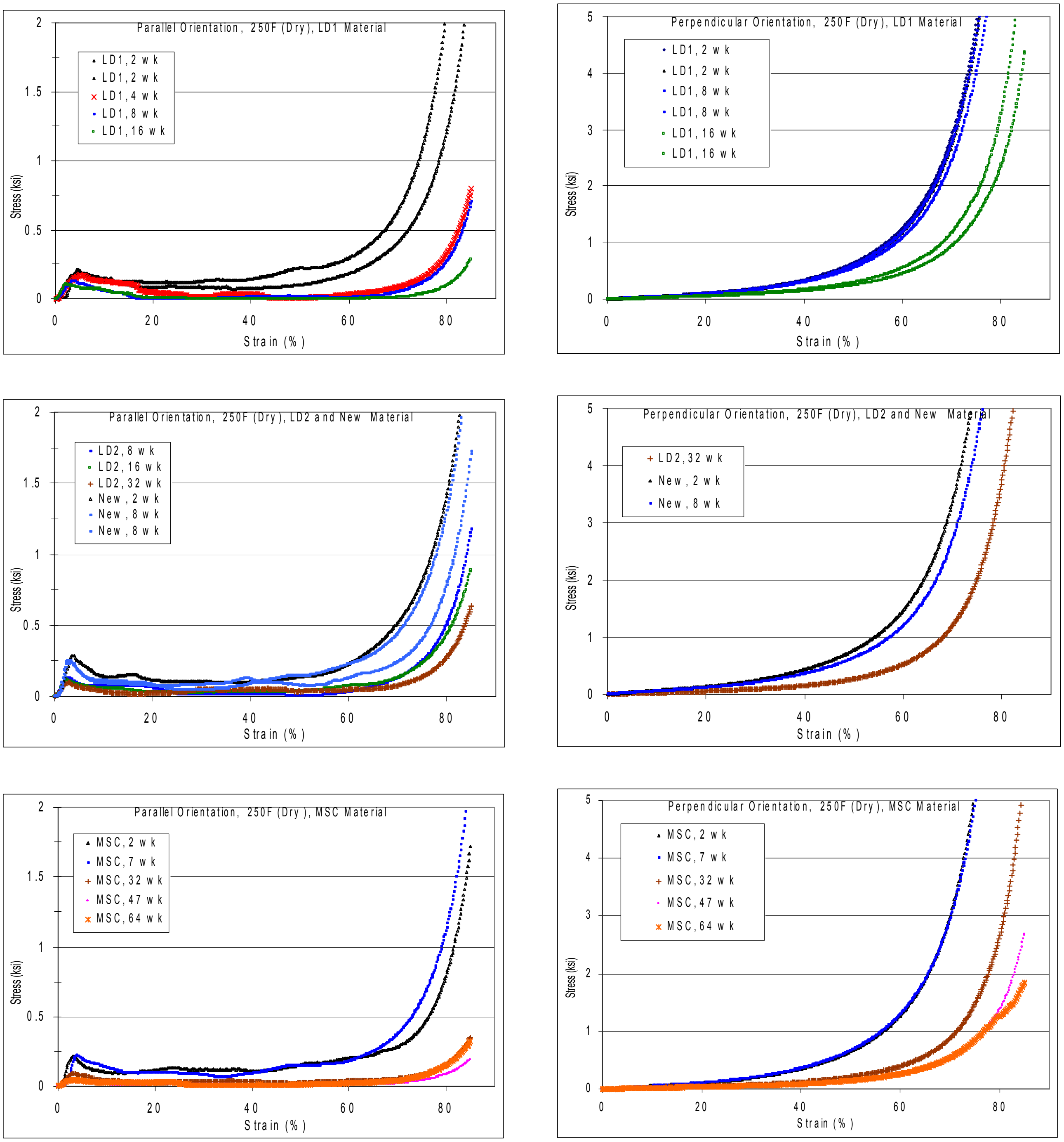
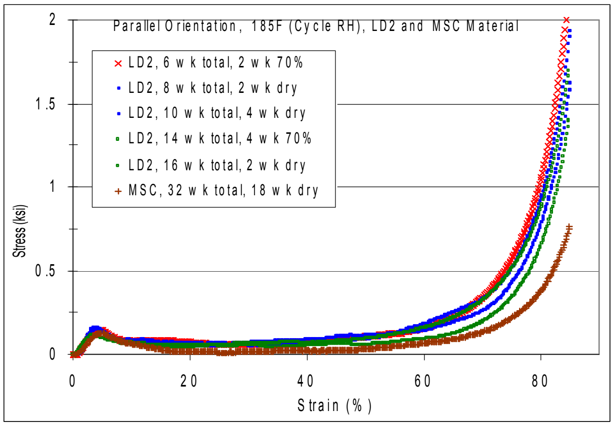
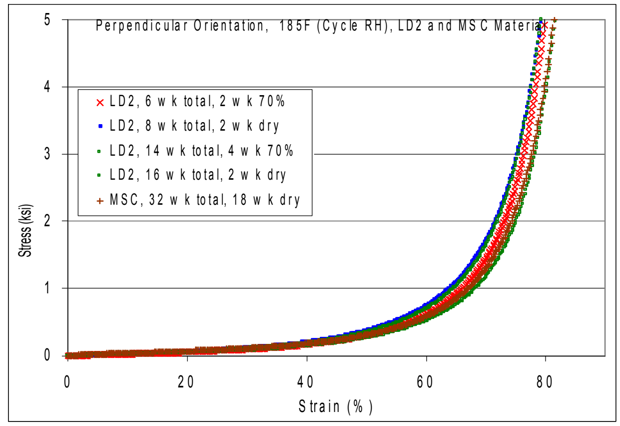


Figure 9. Engineering stress-strain compression curves for fiberboard samples conditioned at 121ºC (250ºF), dry oven.

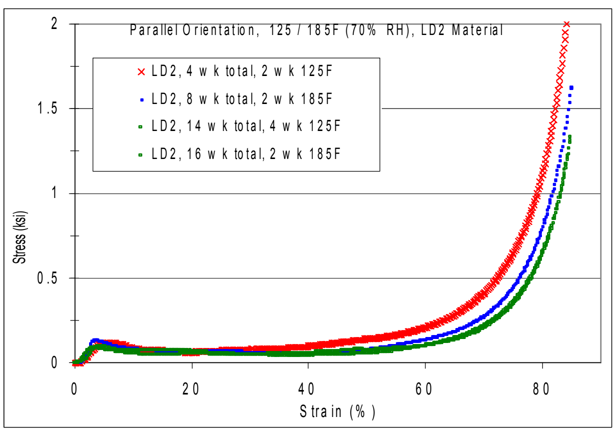


(a)

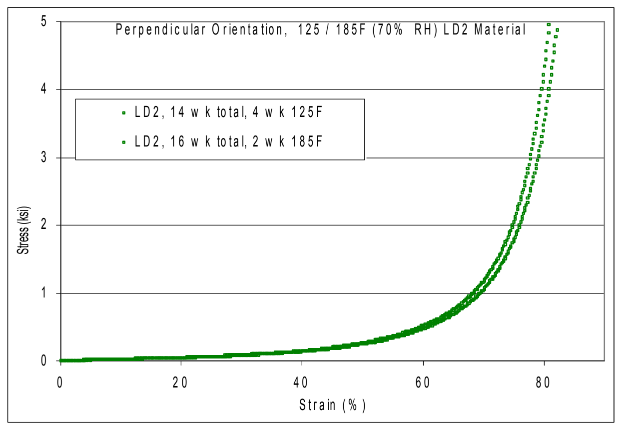


(b)

Figure 10. Engineering stress-strain compression curves for LD2 and MSC fiberboard samples conditioned at 85C (185F), cycled between 70% relative humidity and dry oven.



(a)



(b)

Figure 11. Engineering stress-strain compression curves for LD2 fiberboard samples conditioned at 70% relative humidity, cycled between 51ºC (125ºF) and 85ºC (185ºF).

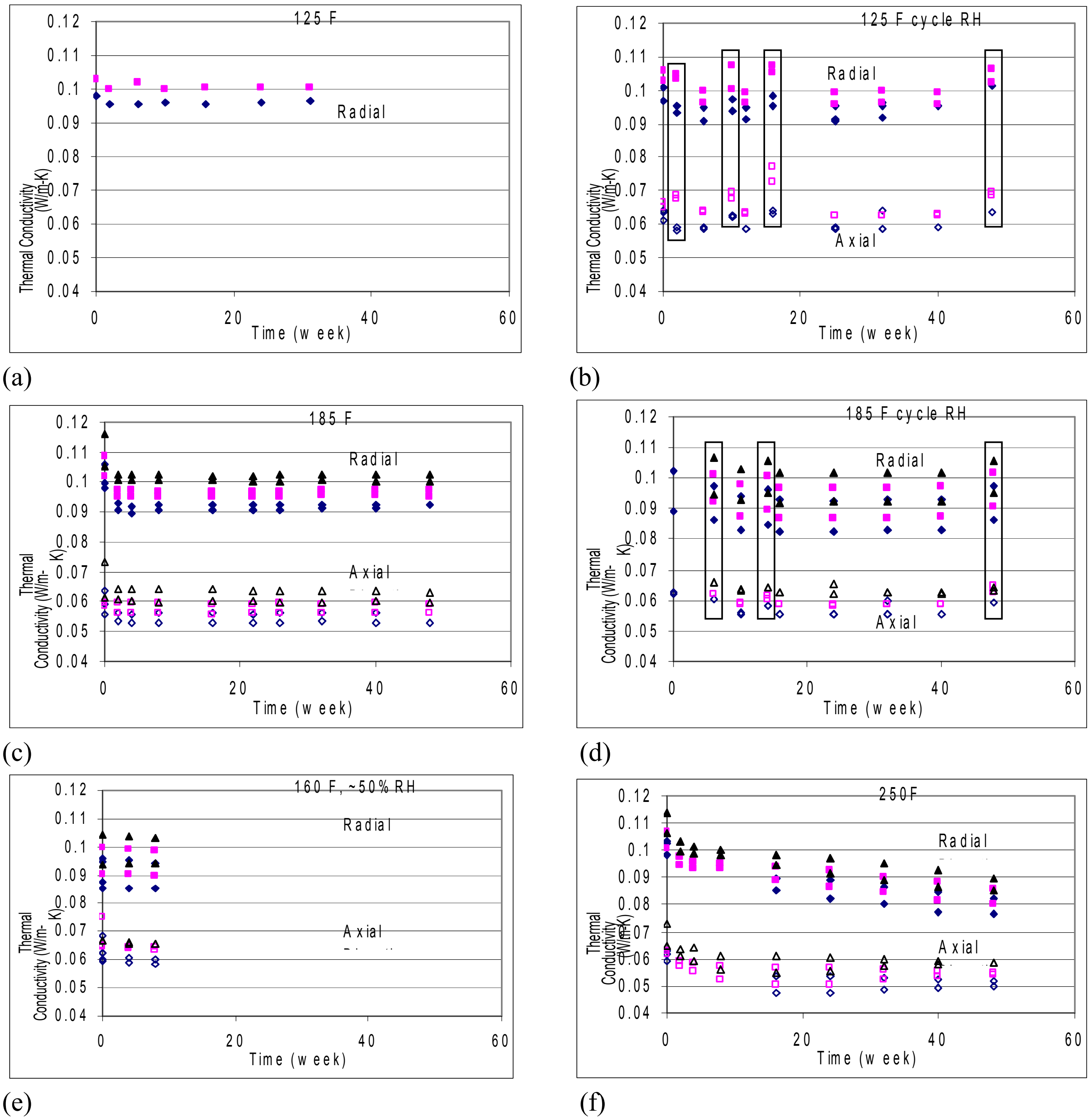


Figure 12. Thermal conductivity data for each conditioning environment. In each plot, the test temperature is indicated by the symbol: diamonds - 25ºC, squares - 51ºC, triangles - 71 or 85ºC. Open symbols denote axial orientation samples, closed symbols denote radial orientation samples. In plots (b) and (d) with the cycling humidity, the data within the boxes are for 70% relative humidity.

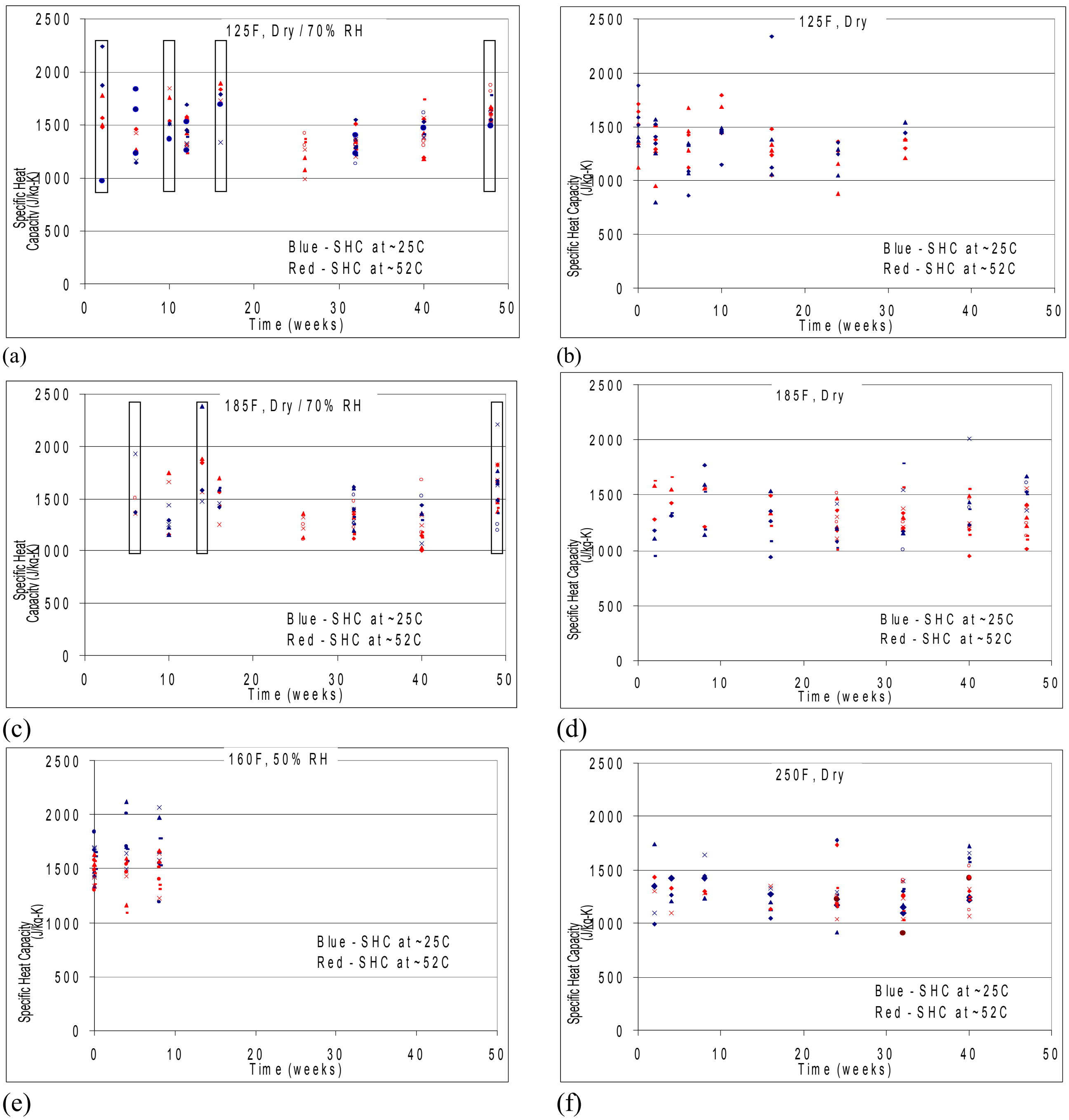
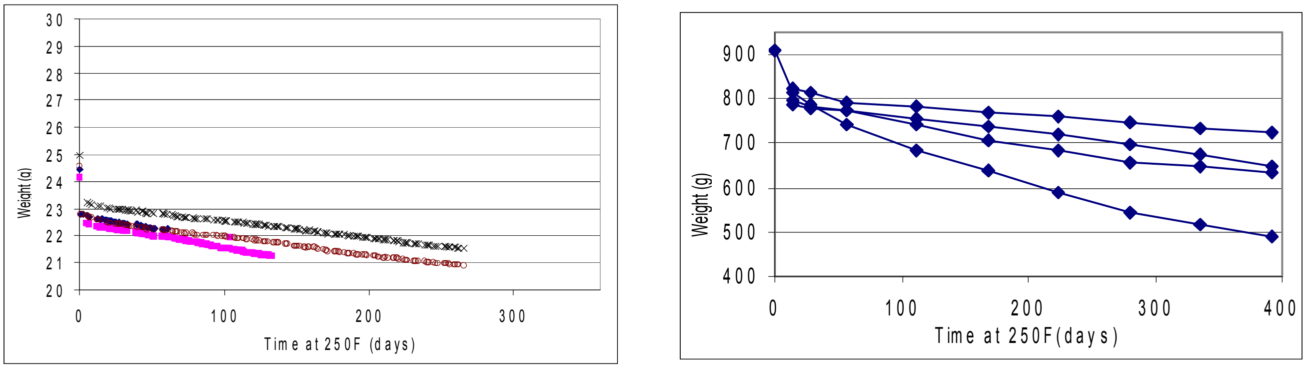


Figure 13. Specific heat capacity data for each conditioning environment. In each plot, the blue symbols are data for a mean temperature of 25ºC (77ºF) and the red symbols are data for a mean temperature of 52ºC (125ºF). For plots (a) and (c) the data within the boxes follow conditioning at 70% relative humidity, and the remaining data follow conditioning in a dry oven.



(a) mass loss samples at 250ºF

(b) thermal conductivity samples at 250ºF

Figure 14. Weight change data at 121ºC (250ºF), dry for mass loss and thermal conductivity samples. The bottom curve for the thermal conductivity samples is for LD2-1A, which was exposed to temperature above 121ºC.

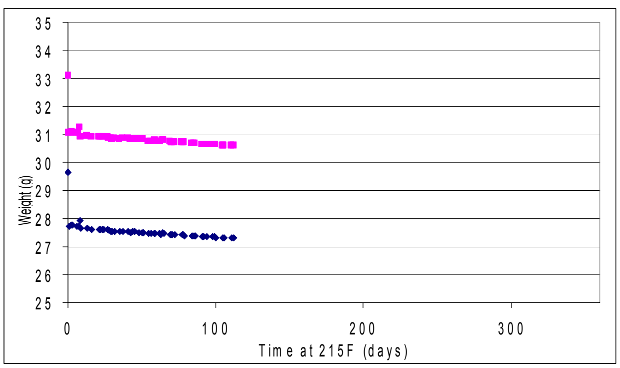


Figure 15. Weight change data at 102ºC (215ºF), dry for mass loss samples.

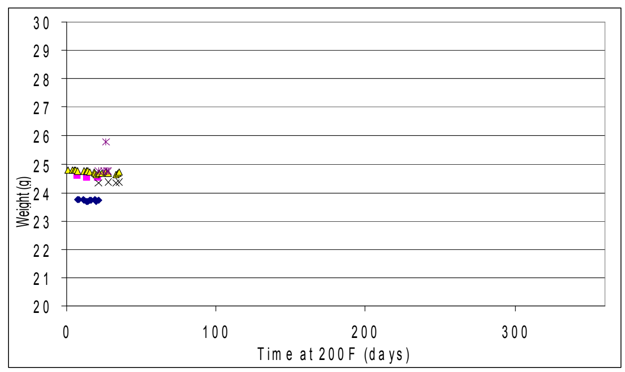
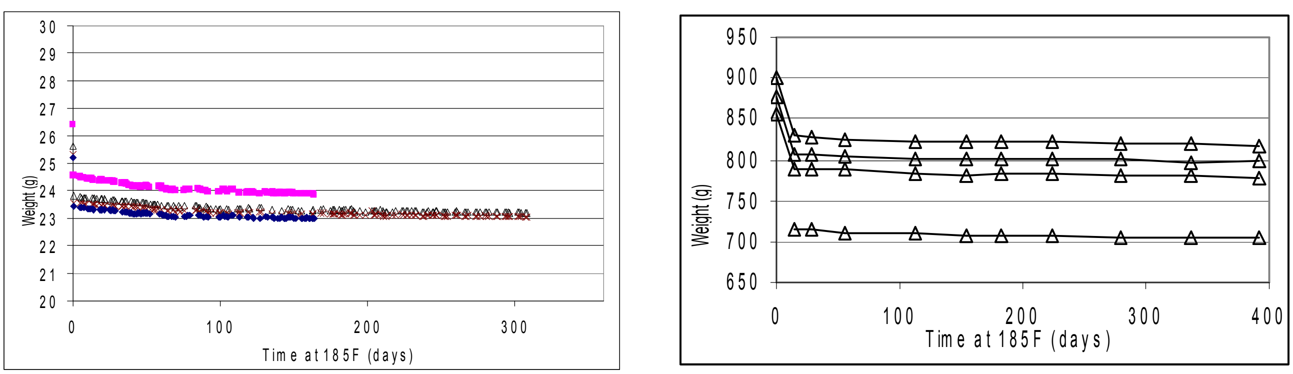


Figure 16. Weight change data at 93ºC (200ºF), dry for mass loss samples.



(a) mass loss samples at 185ºF

(b) thermal conductivity samples at 185ºF

Figure 17. Weight change data at 85ºC (185ºF), dry for mass loss and thermal conductivity samples.

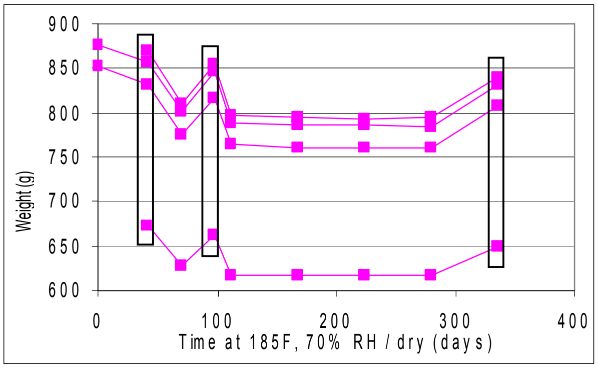
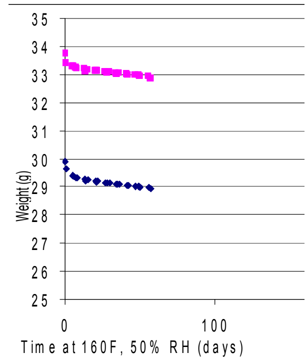
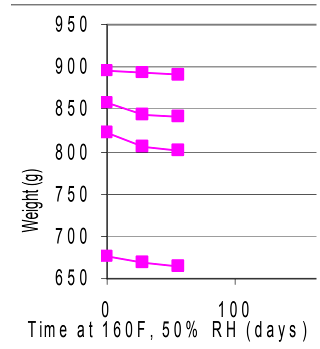


Figure 18. Weight change data at 85ºC (185ºF), cycling humidity for thermal conductivity samples. Symbols within the boxes are data following 70% relative humidity.

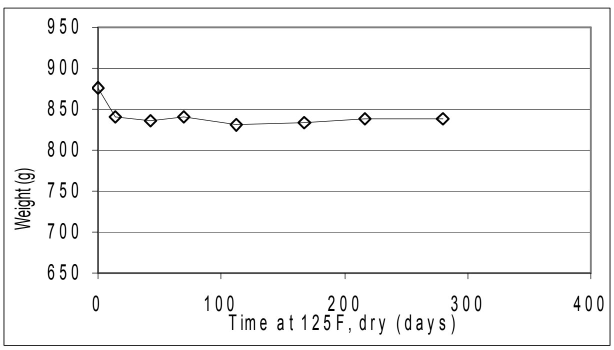


(a) mass loss samples at 160ºF, 50% RH

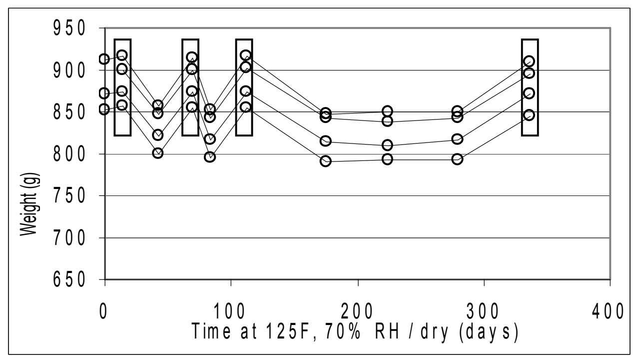


(b) thermal conductivity samples at 160ºF, 50% RH

Figure 19. Weight change data at 71ºC (160ºF), 50% RH for mass loss and thermal conductivity samples.

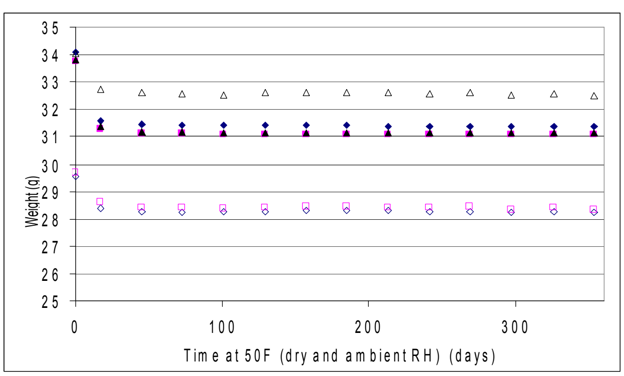


(a) thermal conductivity sample at 125ºF, dry

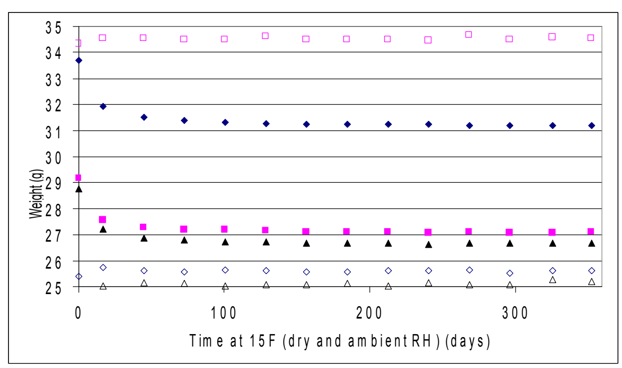


(b) thermal conductivity samples at 125ºF, cycling humidity

Figure 20. Weight change data at 51ºC (125ºF) (dry and cycling humidity) for thermal conductivity samples. Symbols within the boxes are data following 70% relative humidity.

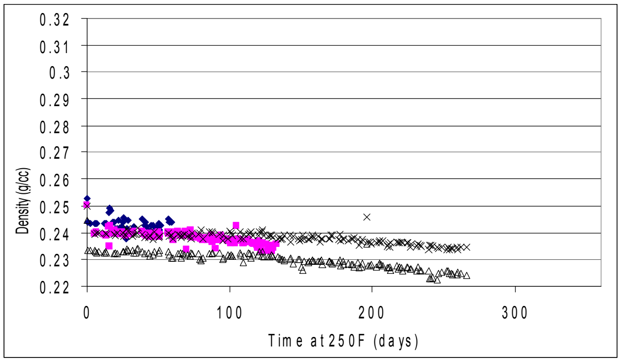


(a) mass loss samples at 50ºF

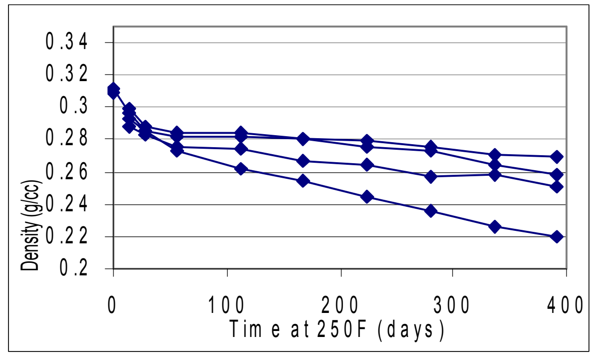


(b) mass loss samples at 15ºF

Figure 21. Weight change data at low temperatures (10ºC / 50ºF and -10ºC / 15ºF) for mass loss samples. Solid symbols are for dry (desiccated samples), open symbols are for ambient humidity samples.



(a) mass loss samples at 250ºF



(b) thermal conductivity samples at 250ºF

Figure 22. Density data at 121ºC (250ºF) for mass loss and thermal conductivity samples. The bottom curve for the thermal conductivity samples is for LD2-1A, which was exposed to temperature above 121ºC.

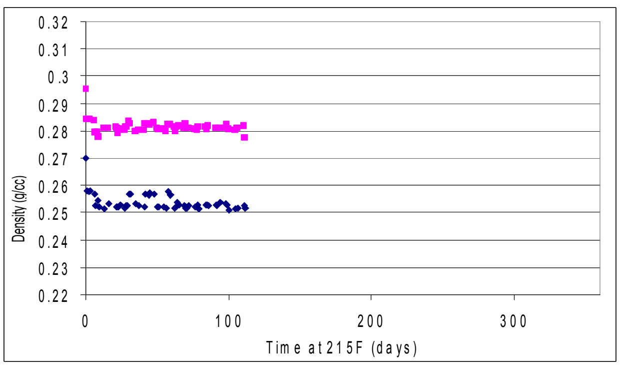


Figure 23. Density data at 102ºC (215ºF) for mass loss samples.

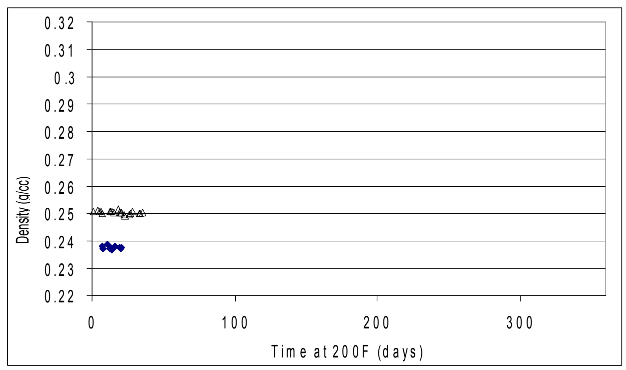
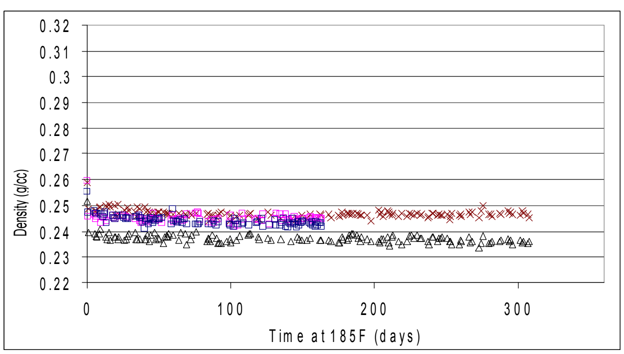
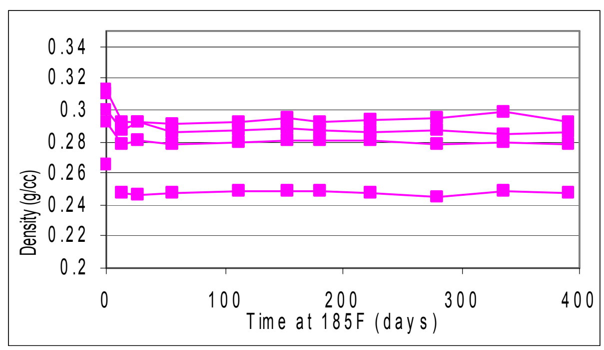


Figure 24. Density data at 93ºC (200ºF) for mass loss samples.



(a) mass loss samples at 185ºF



(b) thermal conductivity samples at 185ºF

Figure 25. Density data at 85ºC (185ºF) for mass loss and thermal conductivity samples.

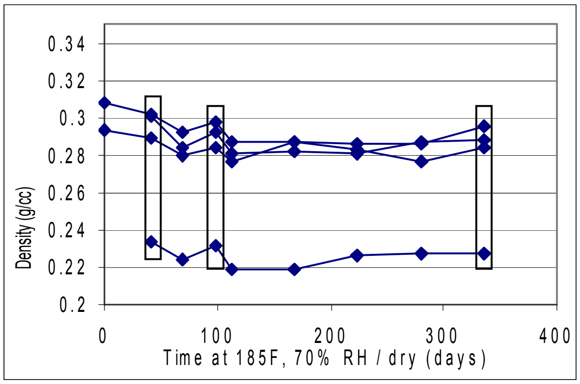
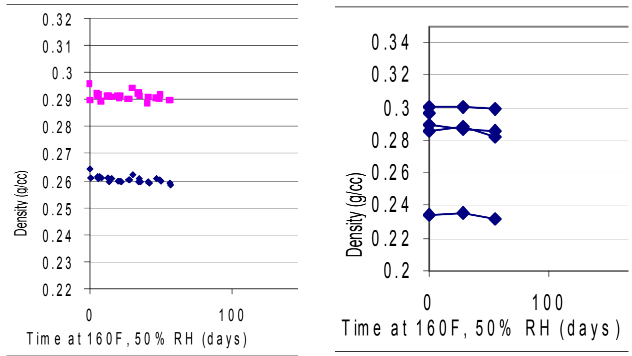


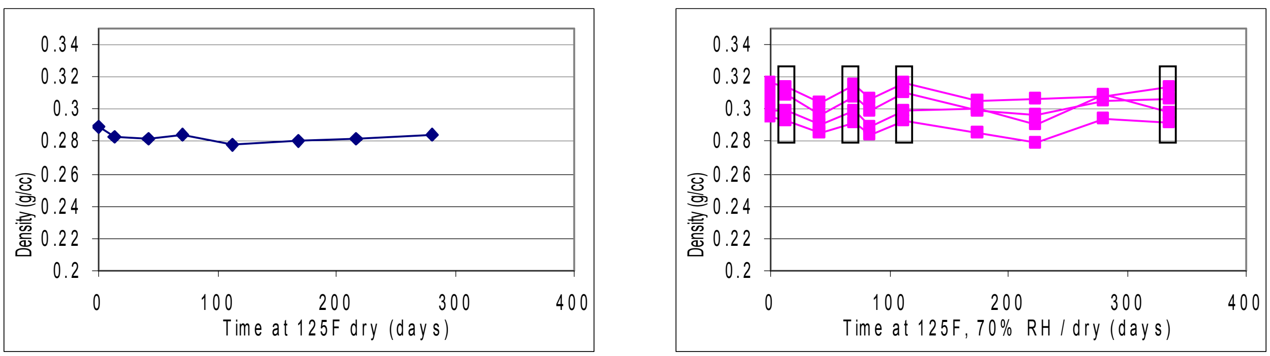
Figure 26. Density data at 85ºC (185ºF), cycling humidity for thermal conductivity samples. Symbols within the boxes are data following 70% relative humidity.



(a) mass loss samples at 160ºF, 50% RH

(b) thermal conductivity samples at 160ºF, 50% RH

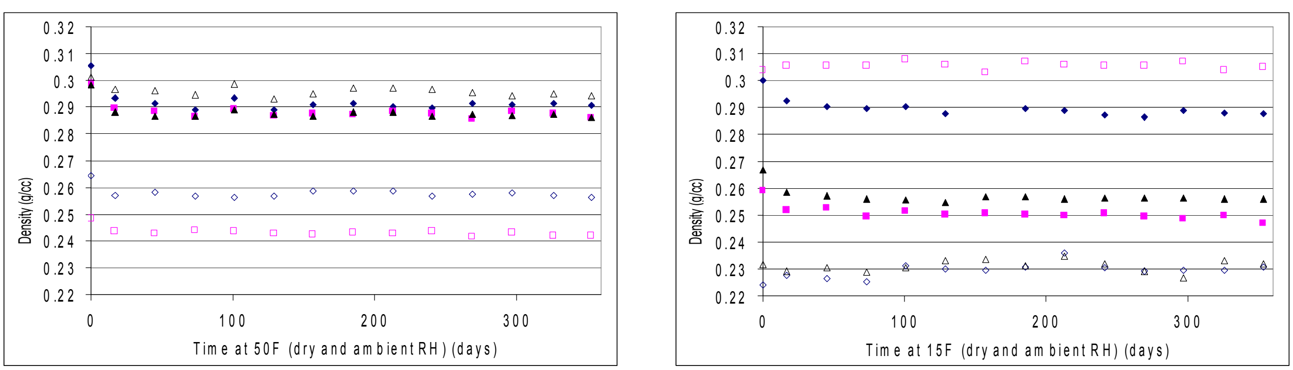
Figure 27. Density data at 71ºC (160ºF), 50% RH for mass loss and thermal conductivity samples.



(a) thermal conductivity sample at 125ºF, dry

(b) thermal conductivity samples at 125ºF, cycling humidity

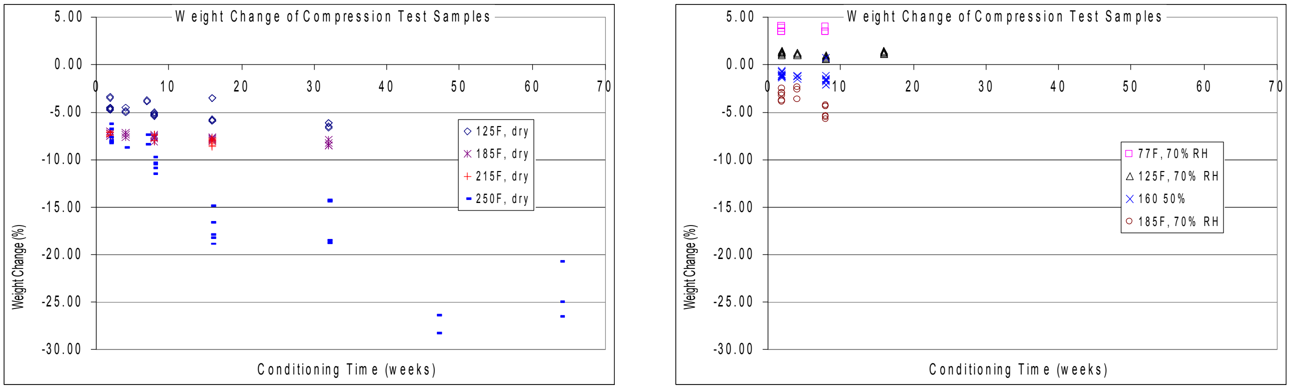
Figure 28. Density data at 51ºC (125ºF) (dry and cycling humidity) for thermal conductivity samples. Symbols within the boxes are data following 70% relative humidity.



(a) mass loss samples at 50ºF

(b) mass loss samples at 15ºF

Figure 29. Density data at low temperatures (10ºC / 50ºF and -10ºC / 15ºF) for mass loss samples. Solid symbols are for dry (desiccated samples), open symbols are for ambient humidity samples.



(a) samples conditioned in dry environments (b) samples conditioned in humid environments

Figure 30. Weight change data from compression test samples.

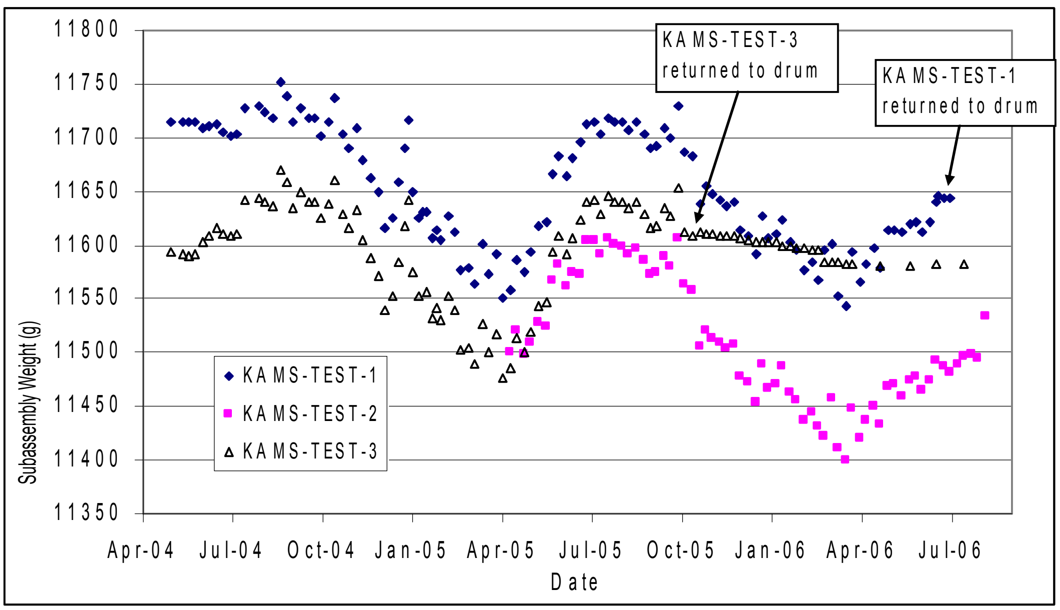


Figure 31. Seasonal weight variation for upper fiberboard subassemblies exposed to ambient temperature and humidity.

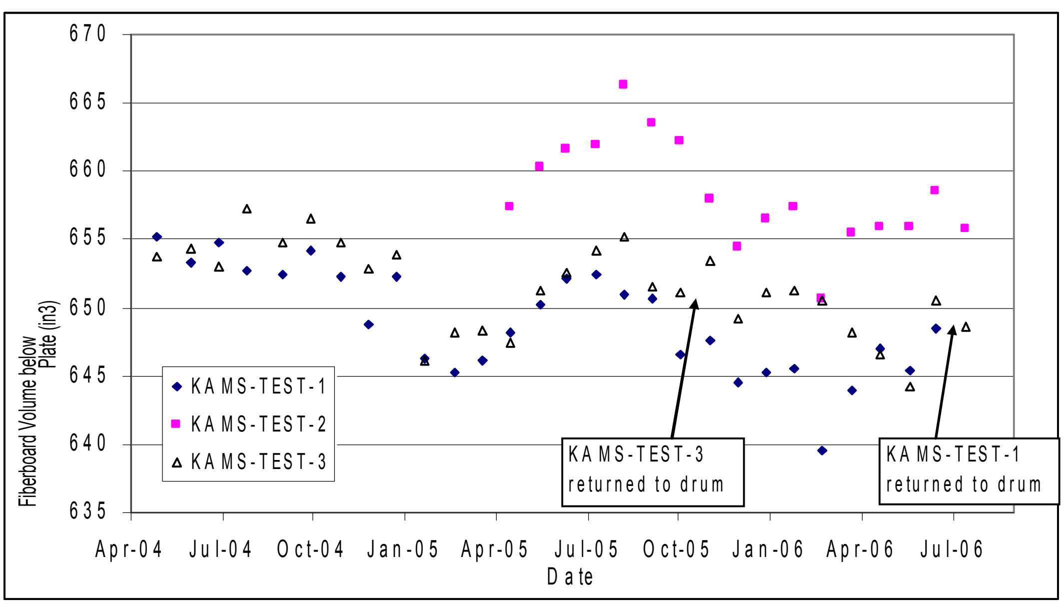


Figure 32. Seasonal variation of subassembly volume below the bearing plate for upper fiberboard subassemblies exposed to ambient temperature and humidity.

Figure 33. Thermal conductivity samples LD2-1A and TC2A following conditioning at 121ºC for 4 weeks, compared to sample TC1A with no conditioning. Note the greater overall darkening and the dark spots on LD2-1A, for which the actual temperature was >121ºC.

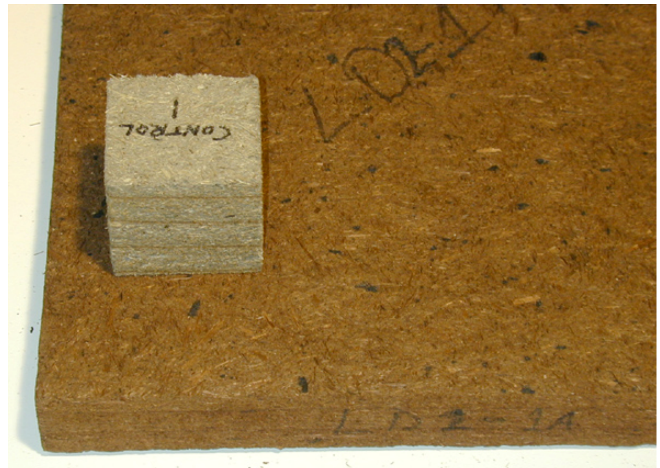


Figure 34. Thermal conductivity sample LD2-1A after conditioning at >121ºC for 21 weeks, compared to a control sample which has seen no elevated temperature.

Figure 35. Sample MSC-4 after compression testing, perpendicular orientation. Sample was conditioned at 121ºC for 47 weeks.

Figure 36. Sample MSC-3 after compression testing, parallel orientation. Sample was conditioned at 121ºC for 47 weeks.

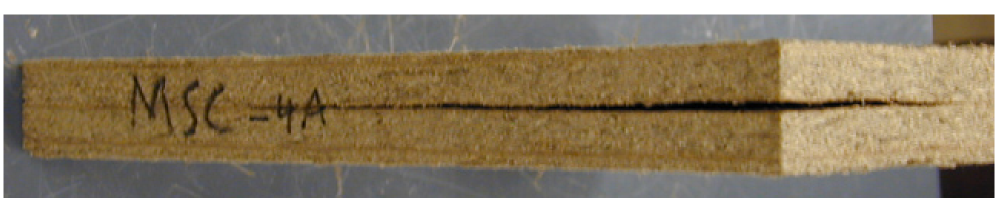


Figure 37. Partial layer separation in thermal conductivity sample MSC-4A after conditioning at 85ºC for 4 weeks.

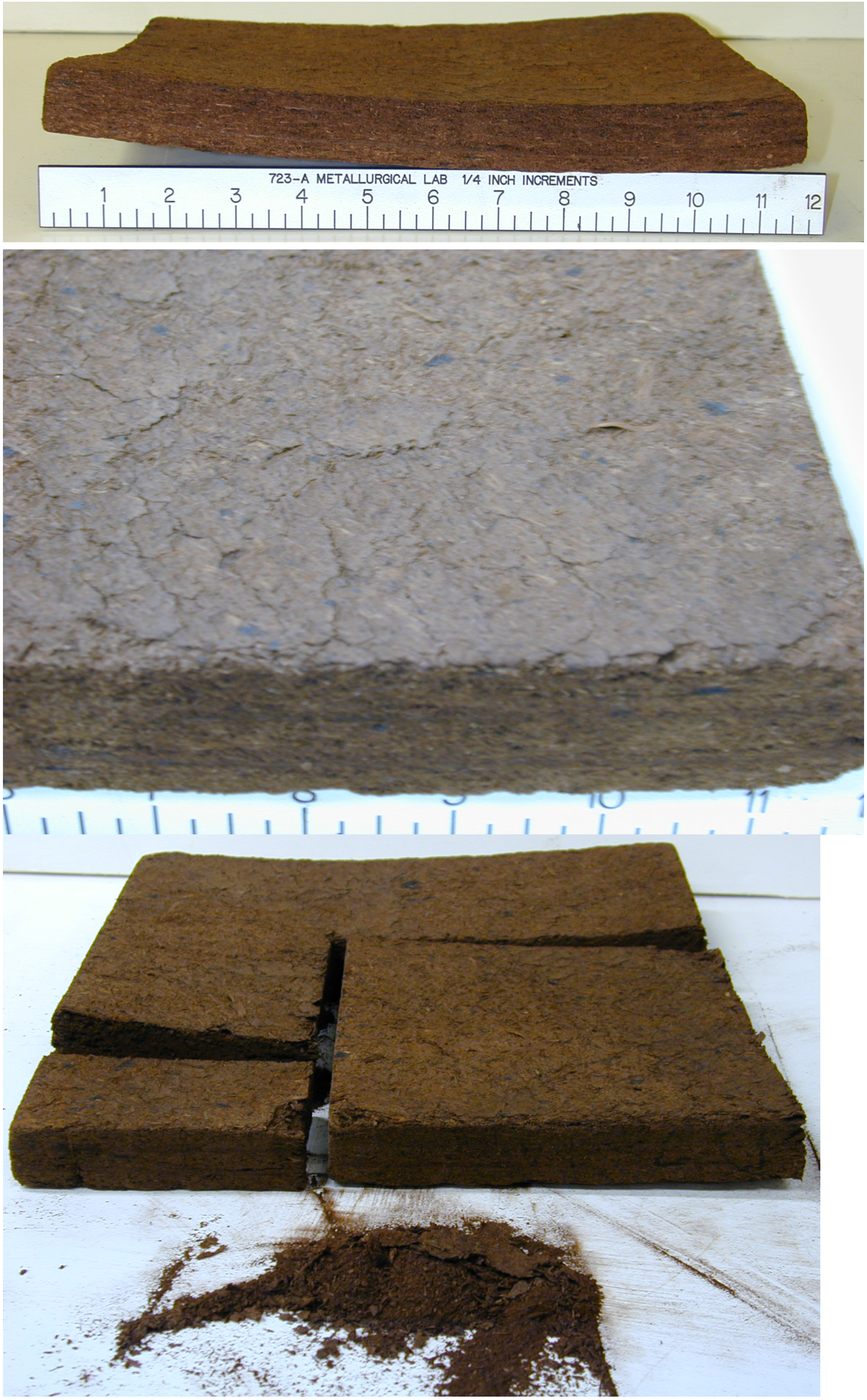
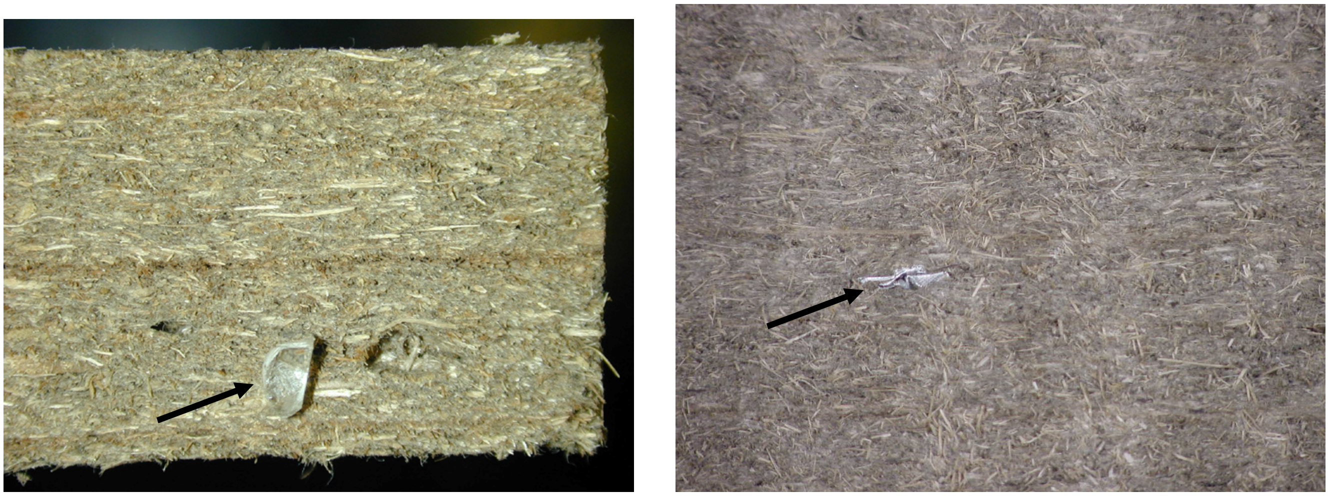


Figure 38. Thermal conductivity sample LD2-1A after conditioning at <121ºC for 56 weeks.

(a) Showing significant warping

(b) Surface detail showing appearance similar to cracked leather.

(c) After cutting to produce a smaller sample with less overall curvature. Note the powdery debris from cutting and scraping the cut surfaces smooth.



(a) (b)

Figure 39. Foreign objects in fiberboard samples. (a) Fragment of glass removed from thermal conductivity sample TC1A. (b) Fragment of aluminum can embedded in thermal conductivity sample TC3R.

Appendices

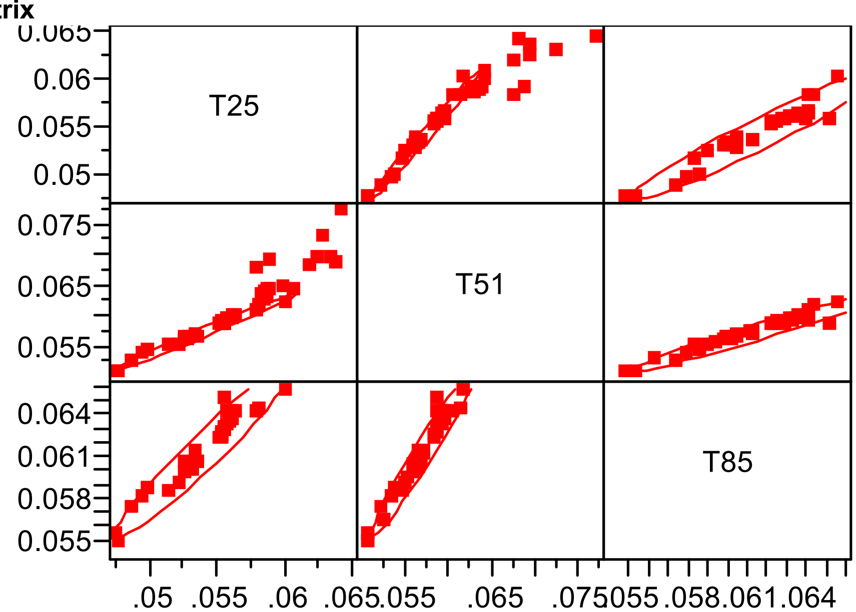
Appendix 1a
Correlation Analysis of Thermal Conductivity Data
Orientation=Axial

Deleted all Time=0 Records; Outlier Screened Data
T25, T51 and T85: Thermal Conductivity (W/m-K) at 25, 51 and 85 deg C

Multivariate Correlations

	T25	T51	T85
T25	1.0000	0.9911	0.9634
T51	0.9911	1.0000	0.9763
T85	0.9634	0.9763	1.0000

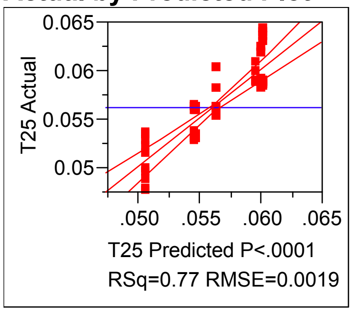
Scatterplot Matrix



Appendix 1b
Regression Analysis of T25 Thermal Conductivity Data
Orientation=Axial

Deleted all Time=0 Records; Outlier Screened Data
T25: Thermal Conductivity (W/m-K) at 25 deg C

Response T25
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.767359
RSquare Adj	0.751314
Root Mean Square Error	0.001885
Mean of Response	0.05627
Observations	63

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.00067941	0.000170	47.8277
Error	58	0.00020598	0.000004	Prob > F
C. Total	62	0.00088539		<.0001

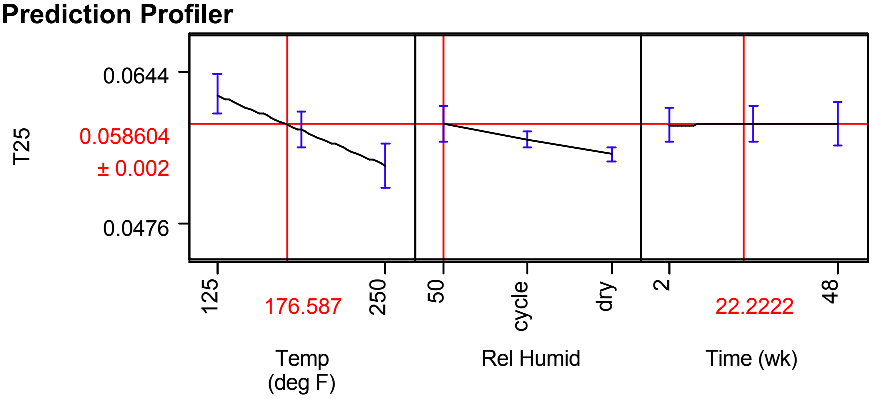
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0679653	0.001443	47.10	<.0001
Temp (deg F)	-0.000063	0.000008	-7.68	<.0001
Rel Humid[50]	0.0016905	0.000683	2.47	0.0163
Rel Humid[cycle]	-7.218e-7	0.000454	-0.00	0.9987
Time (wk)	0.000003	0.000018	0.17	0.8651

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Temp (deg F)	1	1	0.00020930	58.9343	<.0001
Rel Humid	2	2	0.00003929	5.5320	0.0063
Time (wk)	1	1	0.00000010	0.0291	0.8651

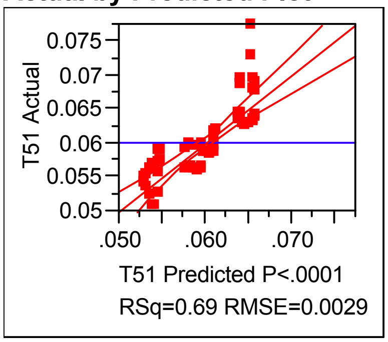
Prediction Profiler



Appendix 1c
Regression Analysis of T51 Thermal Conductivity Data
Orientation=Axial

Deleted all Time=0 Records; Outlier Screened Data
T51: Thermal Conductivity (W/m-K) at 51 deg C

Response T51
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.689628
RSquare Adj	0.67023
Root Mean Square Error	0.002882
Mean of Response	0.060062
Observations	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.00118140	0.000295	35.5511
Error	64	0.00053170	0.000008	Prob > F
C. Total	68	0.00171310		<.0001

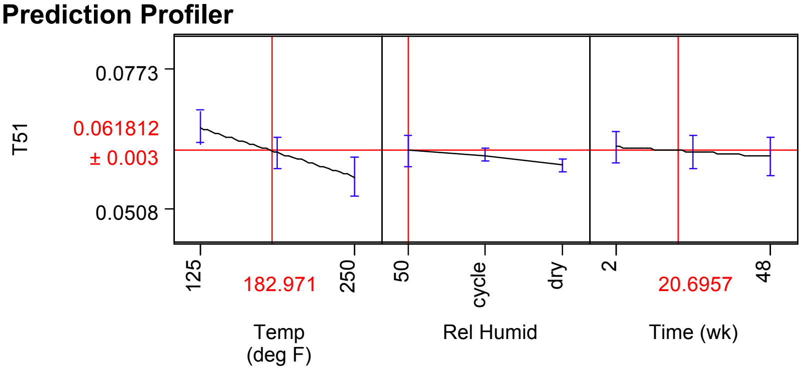
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.075017	0.002122	35.35	<.0001
Temp (deg F)	-0.000074	0.000011	-6.47	<.0001
Rel Humid[50]	0.0012093	0.001037	1.17	0.2478
Rel Humid[cycle]	0.0003376	0.000689	0.49	0.6256
Time (wk)	-0.00004	0.000024	-1.62	0.1101

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Temp (deg F)	1	1	0.00034764	41.8453	<.0001
Rel Humid	2	2	0.00003500	2.1063	0.1300
Time (wk)	1	1	0.00002181	2.6257	0.1101

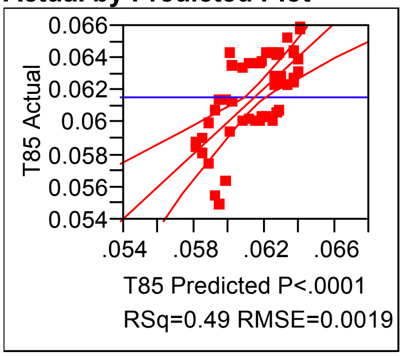
Prediction Profiler



Appendix 1d
Regression Analysis of T85 Thermal Conductivity Data
Orientation=Axial

Deleted all Time=0 Records; Outlier Screened Data
T85: Thermal Conductivity (W/m-K) at 85 deg C

Response T85
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.486479
RSquare Adj	0.451466
Root Mean Square Error	0.001948
Mean of Response	0.061567
Observations	48

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.00015820	0.000053	13.8943
Error	44	0.00016699	0.000004	Prob > F
C. Total	47	0.00032519		<.0001

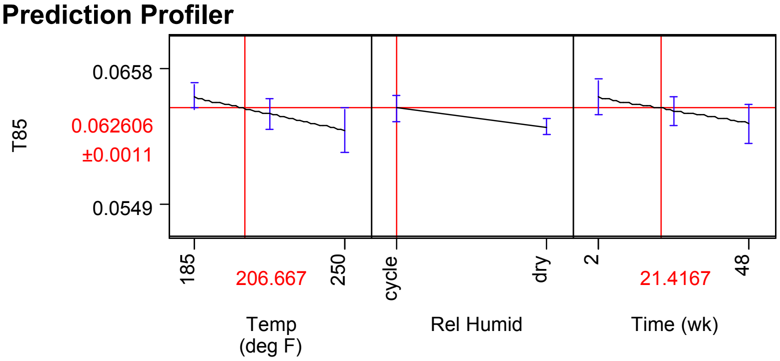
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0713487	0.002128	33.52	<.0001
Temp (deg F)	-0.000041	0.00001	-4.00	0.0002
Rel Humid[cycle]	0.0007339	0.000348	2.11	0.0404
Time (wk)	-0.000045	0.000019	-2.30	0.0260

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Temp (deg F)	1	1	0.00006080	16.0204	0.0002
Rel Humid	1	1	0.00001693	4.4601	0.0404
Time (wk)	1	1	0.00002015	5.3097	0.0260

Prediction Profiler



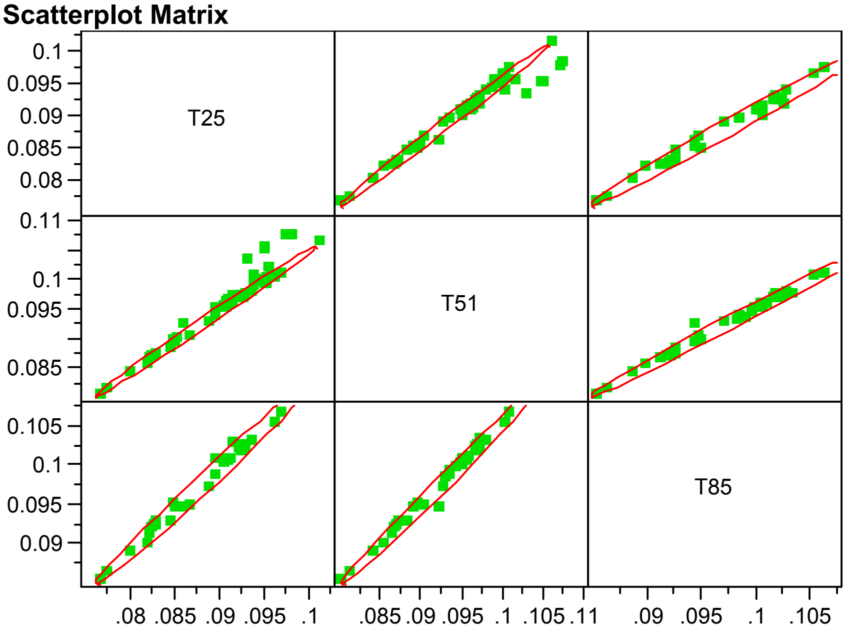
Appendix 2a
Correlation Analysis of Thermal Conductivity Data
Orientation=Radial

Deleted all Time=0 Records; Outlier Screened Data
T25, T51 and T85: Thermal Conductivity (W/m-K) at 25, 51 and 85 deg C

Multivariate Correlations

	T25	T51	T85
T25	1.0000	0.9961	0.9928
T51	0.9961	1.0000	0.9946
T85	0.9928	0.9946	1.0000

Scatterplot Matrix

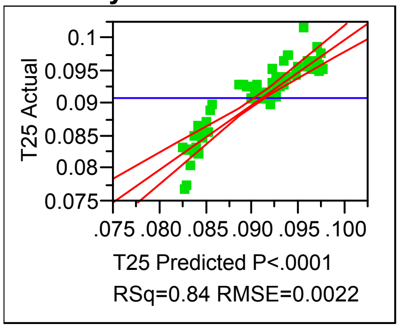


Appendix 2b
Regression Analysis of T25 Thermal Conductivity Data
Orientation=Radial

Deleted all Time=0 Records; Outlier Screened Data

T25: Thermal Conductivity (W/m-K) at 25 deg C

Actual by Predicted Plot



Summary of Fit

RSquare	0.837333
RSquare Adj	0.818356
Root Mean Square Error	0.00223
Mean of Response	0.090806
Observations	68

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.00153604	0.000219	44.1218
Error	60	0.00029840	0.000005	Prob > F
C. Total	67	0.00183444		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1049483	0.001399	75.01	<.0001
Temp (deg F)	-0.000087	0.000008	-10.36	<.0001
Rel Humid[50]	-0.000182	0.000838	-0.22	0.8287
Rel Humid[cycle]	0.0010852	0.00053	2.05	0.0450
Time (wk)	-0.000047	0.000022	-2.17	0.0339

w/ Material Source Terms

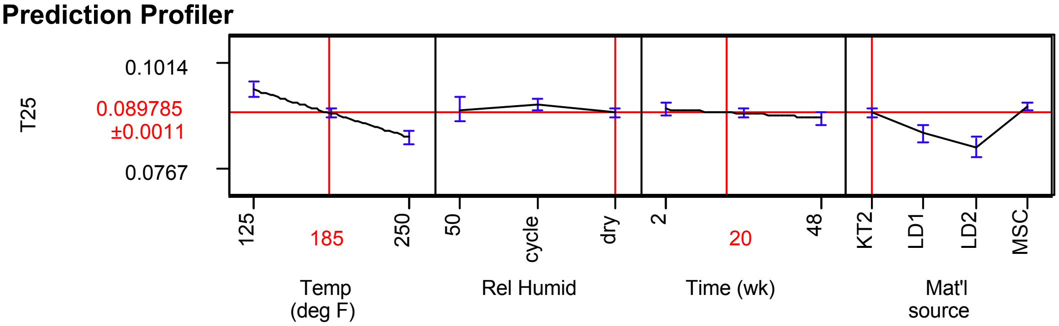
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Mat'l source&Random	0.000013	72.757
Residual	0.000005	27.243
Total	0.000018	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp (deg F)	0.00053	0.00053	1	107.4082	<.0001
Rel Humid	0.00004	0.00002	2	3.6531	0.0318
Time (wk)	0.00002	0.00002	1	4.7150	0.0339
Mat'l source&Random	0.00054	0.00018	3	36.3016	<.0001

Prediction Profiler

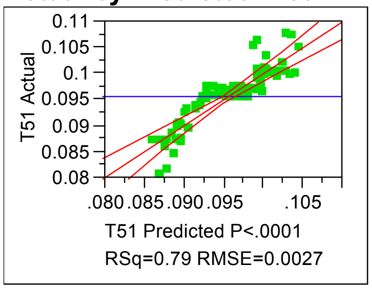


Appendix 2c
Regression Analysis of T51 Thermal Conductivity Data
Orientation=Radial

Deleted all Time=0 Records; Outlier Screened Data

T51: Thermal Conductivity (W/m-K) at 51 deg C

Actual by Predicted Plot



Summary of Fit

RSquare	0.788018
RSquare Adj	0.765535
Root Mean Square Error	0.002743
Mean of Response	0.095672
Observations	74

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.00184665	0.000264	35.0496
Error	66	0.00049676	0.000008	Prob > F
C. Total	73	0.00234341		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1099562	0.001618	67.95	<.0001
Temp (deg F)	-0.000079	0.000009	-8.75	<.0001
Rel Humid[50]	-0.000916	0.001028	-0.89	0.3759
Rel Humid[cycle]	0.0016799	0.000649	2.59	0.0119
Time (wk)	-0.000116	0.000024	-4.90	<.0001

w/ Material Source Terms

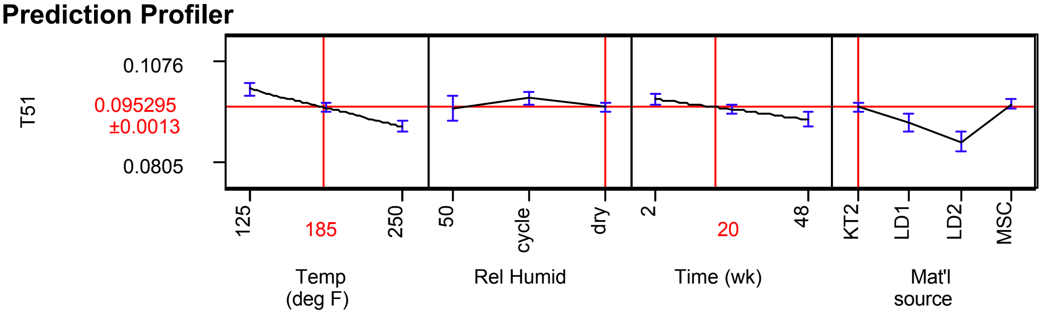
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Mat'l source&Random	0.000012	62.398
Residual	0.000008	37.602
Total	0.00002	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp (deg F)	0.00058	0.00058	1	76.6190	<.0001
Rel Humid	0.00006	0.00003	2	4.2424	0.0185
Time (wk)	0.00018	0.00018	1	24.0433	<.0001
Mat'l source&Random	0.00056	0.00019	3	24.8168	<.0001

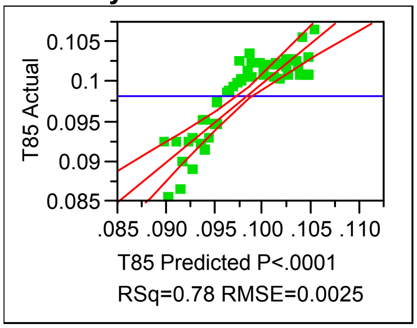
Prediction Profiler



Appendix 2d
Regression Analysis of T85 Thermal Conductivity Data
Orientation=Radial

Deleted all Time=0 Records; Outlier Screened Data
T85: Thermal Conductivity (W/m-K) at 85 deg C

Actual by Predicted Plot



Summary of Fit

RSquare	0.778076
RSquare Adj	0.751012
Root Mean Square Error	0.002537
Mean of Response	0.098279
Observations	47

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.00092546	0.000185	28.7496
Error	41	0.00026396	0.000006	Prob > F
C. Total	46	0.00118942		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.11926	0.0028	42.59	<.0001
Temp (deg F)	-0.000094	0.000014	-6.88	<.0001
Rel Humid[cycle]	0.0005422	0.000607	0.89	0.3767
Time (wk)	-0.000154	0.000026	-5.87	<.0001

w/ Material Source Terms

Variance Component Estimates

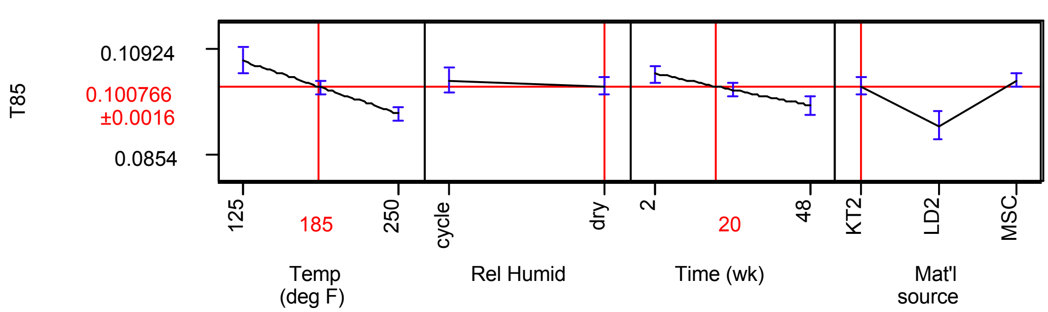
Component	Var Comp Est	Percent of Total
Mat'l source&Random	0.000016	70.750
Residual	0.000006	29.250
Total	0.000022	100.000

These estimates based on equating Mean Squares to Expected Value.

Tests wrt Random Effects

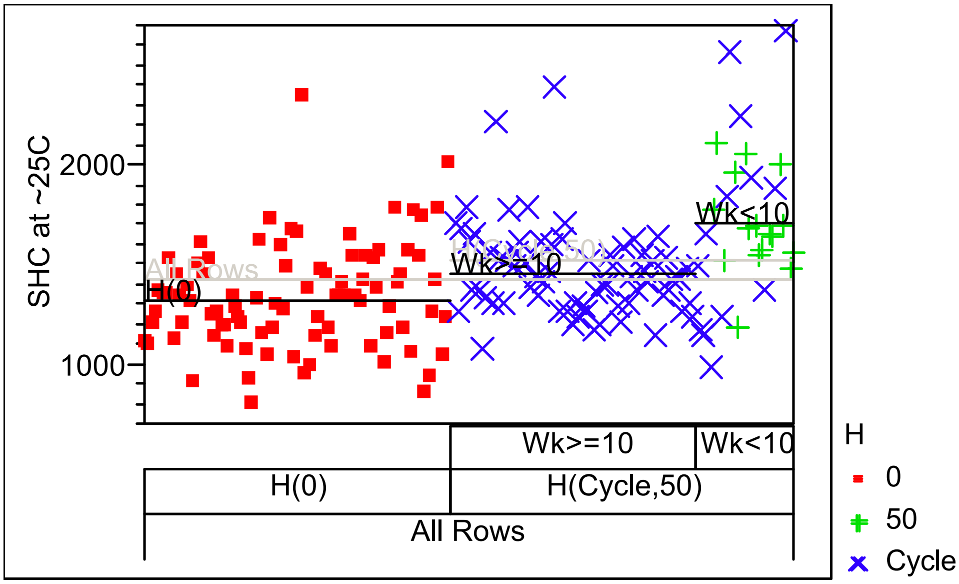
Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp (deg F)	0.00031	0.00031	1	47.3972	<.0001
Rel Humid	5.14e-6	5.14e-6	1	0.7989	0.3767
Time (wk)	0.00022	0.00022	1	34.4999	<.0001
Mat'l source&Random	0.00038	0.00019	2	29.3362	<.0001

Prediction Profiler



Appendix 3a
Partition Analysis of Specific Heat Capacity at 25 Deg C

Color Coded by Humidity
Deleted all Time=0 Records



All Rows

Count	188
Mean	1433.75
Std Dev	299.58125

H(0)

Count	89
Mean	1330.8315
Std Dev	260.07019

H(Cycle,50)

Count	99
Mean	1526.2727
Std Dev	303.73262

Wk>=10

Count	71
Mean	1453.8169
Std Dev	217.5661

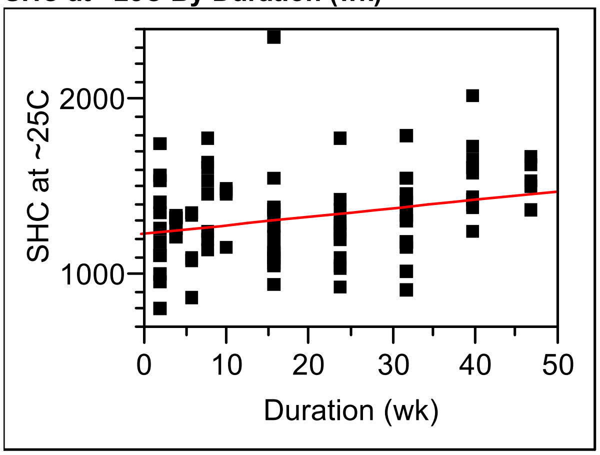
Wk<10

Count	28
Mean	1710
Std Dev	404.122

Appendix 3b
Regression Analysis of Specific Heat Capacity at 25 Deg C
Humidity= 0%

Deleted all Time=0 Records

SHC at ~25C By Duration (wk)



Linear Fit

SHC at ~25C = 1234.7099 + 4.8968621 Duration (wk)

Summary of Fit

RSquare	0.071264
RSquare Adj	0.060589
Root Mean Square Error	252.0684
Mean of Response	1330.831
Observations	89

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	424163.4	424163	6.6757
Error	87	5527849.0	63538	Prob > F
C. Total	88	5952012.5		0.0114

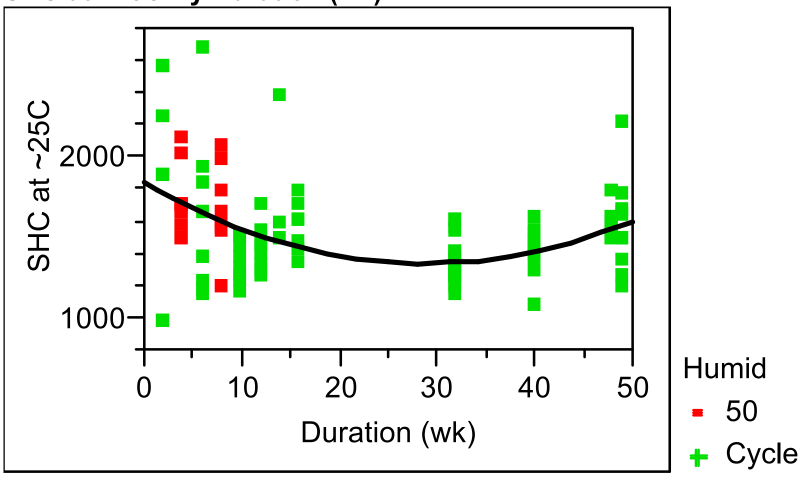
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1234.7099	45.80333	26.96	<.0001
Duration (wk)	4.8968621	1.895264	2.58	0.0114

Appendix 3c
Regression Analysis of Specific Heat Capacity at 25 Deg C
Humidity= 50% and Cycle Combined

Deleted all Time=0 Records

SHC at ~25C By Duration (wk)



Polynomial Fit Degree=2

SHC at ~25C = 1581.8085 - 9.4671405 Duration (wk) + 0.6012846 (Duration (wk)-21.1429)^2

Summary of Fit

RSquare	0.178779
RSquare Adj	0.16167
Root Mean Square Error	278.0987
Mean of Response	1526.273
Observations	99

Analysis of Variance

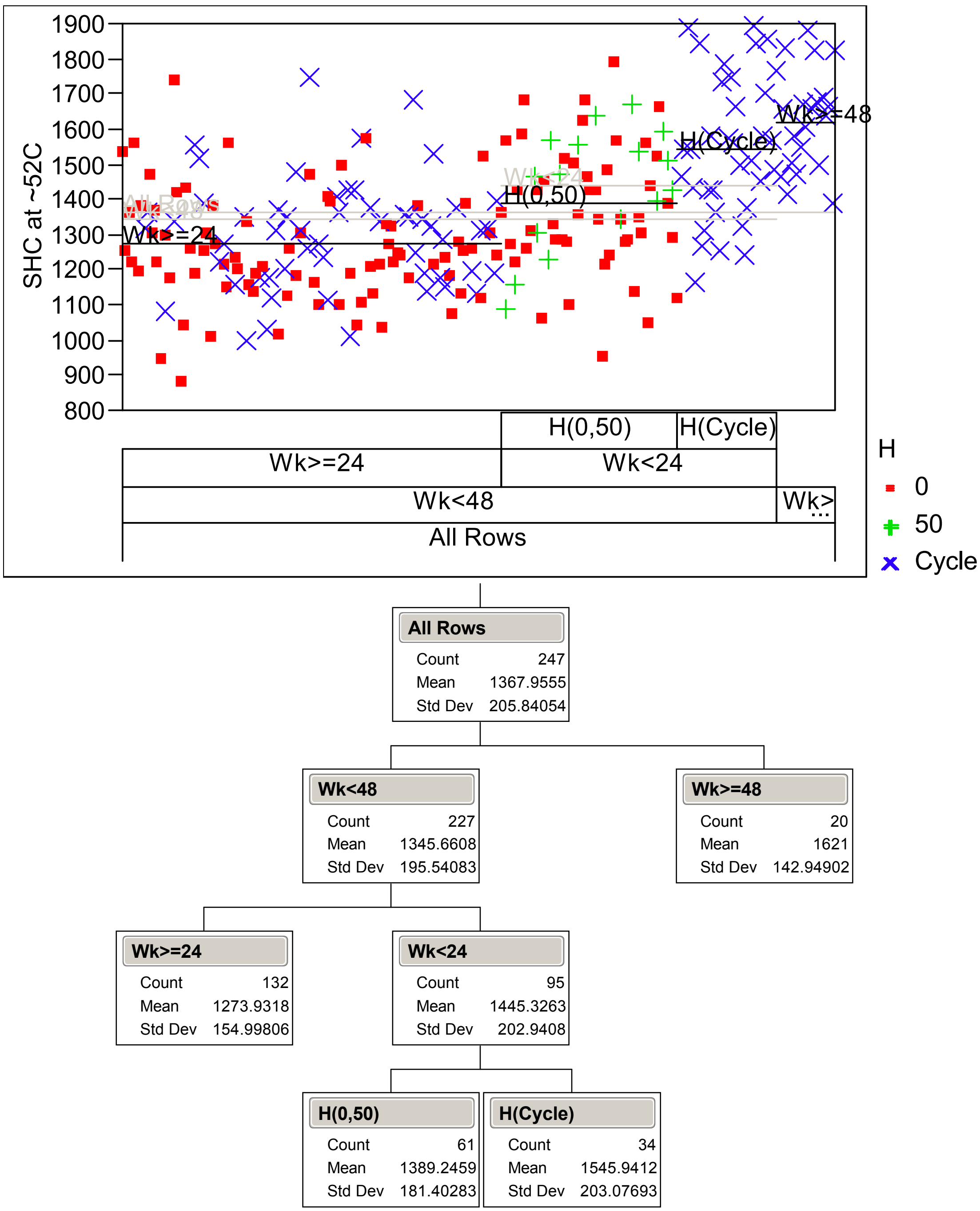
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1616310.1	808155	10.4495
Error	96	7424533.5	77339	Prob > F
C. Total	98	9040843.6		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1581.8085	49.17889	32.16	<.0001
Duration (wk)	-9.46714	2.199214	-4.30	<.0001
(Duration (wk)-21.1429)^2	0.6012846	0.154923	3.88	0.0002

Appendix 4a
Partition Analysis of Specific Heat Capacity at 52 Deg C

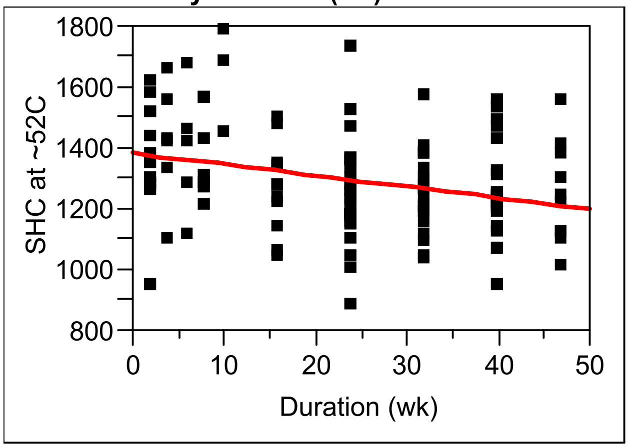
Color Coded by Humidity
Deleted all Time=0 Records



Appendix 4b
Regression Analysis of Specific Heat Capacity at 52 Deg C
Humidity= 0%

Deleted all Time=0 Records

SHC at ~52C By Duration (wk)



Linear Fit
SHC at ~52C = 1386.9669 - 3.6562043 Duration (wk)

Summary of Fit

RSquare	0.090503
RSquare Adj	0.082987
Root Mean Square Error	166.3318
Mean of Response	1298.683
Observations	123

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	333117.8	333118	12.0406
Error	121	3347616.8	27666	Prob > F
C. Total	122	3680734.6		0.0007

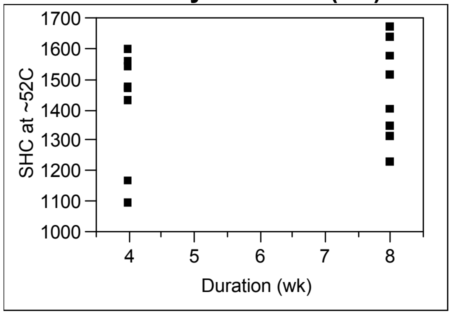
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1386.9669	29.53379	46.96	<.0001
Duration (wk)	-3.656204	1.053675	-3.47	0.0007

Appendix 4c
Regression Analysis of Specific Heat Capacity at 52 Deg C
Humidity= 50%

Deleted all Time=0 Records

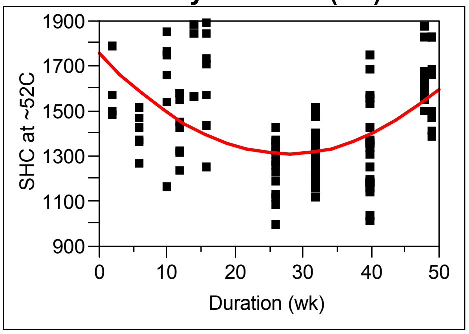
SHC at ~52C By Duration (wk)



Appendix 4d
Regression Analysis of Specific Heat Capacity at 52 Deg C
Humidity= Cycle

Deleted all Time=0 Records

SHC at ~52C By Duration (wk)



Polynomial Fit Degree=2

SHC at ~52C = 1450.977 - 5.4017841 Duration (wk) + 0.5794641 (Duration (wk)-23.0968)^2

Summary of Fit

RSquare	0.244952
RSquare Adj	0.23057
Root Mean Square Error	192.104
Mean of Response	1436.593
Observations	108

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1257093.4	628547	17.0320
Error	105	3874912.6	36904	Prob > F
C. Total	107	5132006.1		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1450.977	41.25789	35.17	<.0001
Duration (wk)	-5.401784	1.514378	-3.57	0.0005
(Duration (wk)-23.0968)^2	0.5794641	0.099648	5.82	<.0001

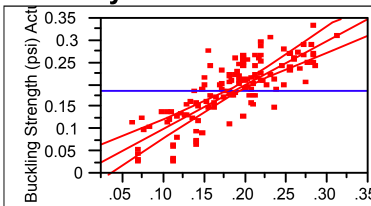
Appendix 5a
Regression Analysis of Buckling Strength (psi) for Parallel Orientation

Outliers deleted

Response Buckling Strength (psi)

Whole Model

Actual by Predicted Plot



Buckling Strength (psi)
Predicted P<.0001 RSq=0.67
RMSE=0.0417

Summary of Fit

RSquare	0.667094
RSquare Adj	0.648452
Root Mean Square Error	0.041663
Mean of Response	0.186308
Observations	133

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.43479764	0.062114	35.7831
Error	125	0.21698072	0.001736	Prob > F
C. Total	132	0.65177836		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3567443	0.016335	21.84	<.0001
Temp	-0.000613	0.000083	-7.39	<.0001
Humidity	-0.001431	0.000115	-12.45	<.0001

w/Random Sample Source Terms

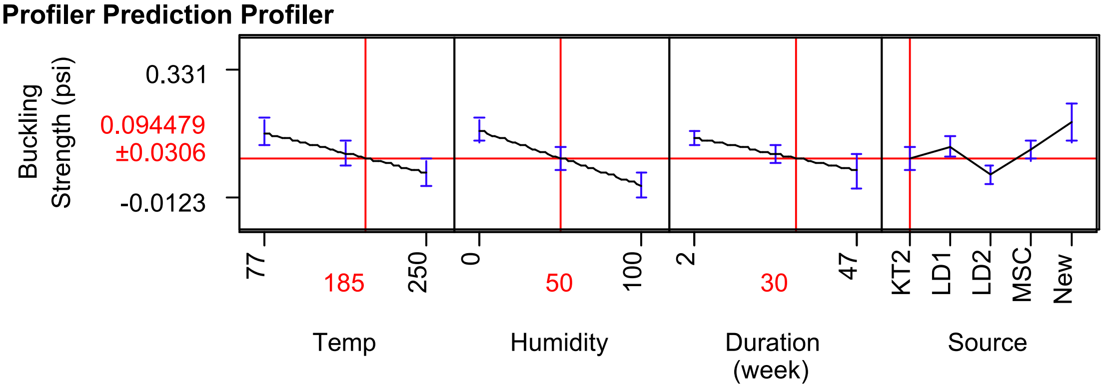
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Source&Random	0.001264	42.134
Residual	0.001736	57.866
Total	0.003	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp	0.09473	0.09473	1	54.5732	<.0001
Humidity	0.26892	0.26892	1	154.9223	<.0001
Duration (week)	0.02617	0.02617	1	15.0764	0.0002
Source&Random	0.12469	0.03117	4	17.9588	<.0001

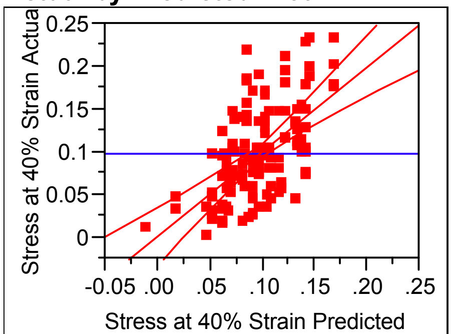
Profiler Prediction Profiler



Appendix 5b
Regression Analysis of Stress at 40% Strain for Parallel Orientation

Outliers deleted

Response Stress at 40% Strain
Whole Model
Actual by Predicted Plot



P<.0001 RSq=0.35
RMSE=0.0447

Summary of Fit

RSquare	0.346566
RSquare Adj	0.331369
Root Mean Square Error	0.044655
Mean of Response	0.097887
Observations	133

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.13642806	0.045476	22.8061
Error	129	0.25722925	0.001994	Prob > F
C. Total	132	0.39365731		<.0001

Parameter Estimates

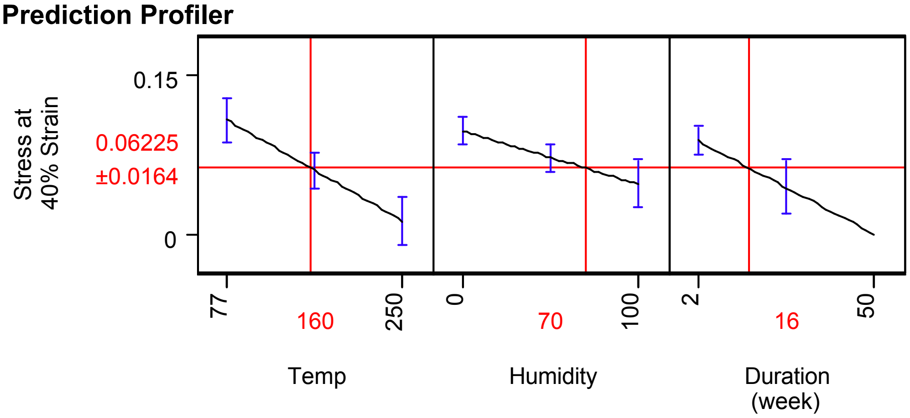
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2165695	0.015669	13.82	<.0001
Temp	-0.000557	0.000084	-6.67	<.0001
Humidity	-0.000509	0.000121	-4.20	<.0001
Duration (week)	-0.001847	0.000503	-3.67	0.0003

Random Source Terns were not significant

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Temp	1	1	0.08868329	44.4745	<.0001
Humidity	1	1	0.03514233	17.6238	<.0001
Duration (week)	1	1	0.02692003	13.5003	0.0003

Prediction Profiler



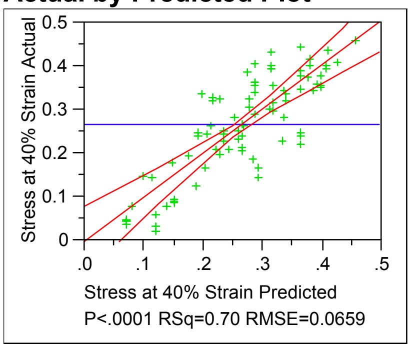
Appendix 5c
Regression Analysis of Stress at 40% Strain for Perpendicular Orientation

Outliers deleted

Response Stress at 40% Strain

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.70262
RSquare Adj	0.675586
Root Mean Square Error	0.065859
Mean of Response	0.266859
Observations	85

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.7891074	0.112730	25.9897
Error	77	0.3339850	0.004337	Prob > F
C. Total	84	1.1230923		<.0001

Parameter Estimates

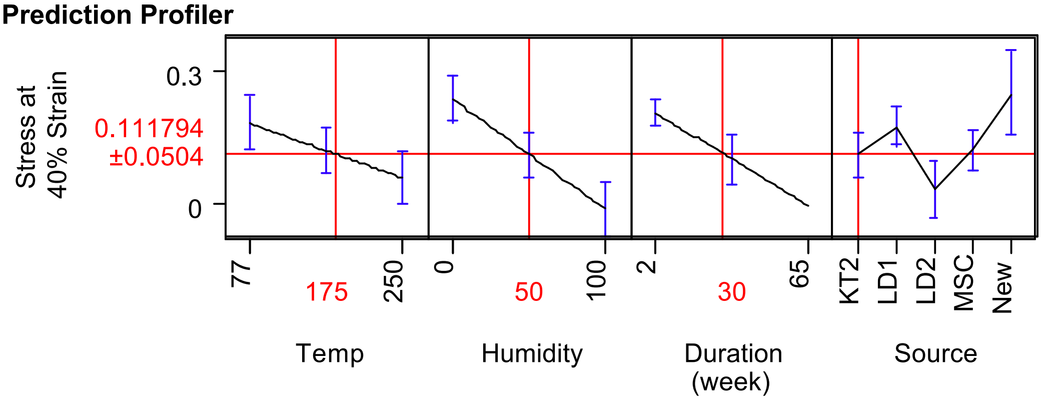
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4832843	0.030857	15.66	<.0001
Temp	-0.000703	0.000156	-4.49	<.0001
Humidity	-0.002458	0.000221	-11.13	<.0001
Duration (week)	-0.003332	0.000816	-4.08	0.0001

w/Random Sample Source Terms

Variance Component Estimates

Component	Var Comp Est	Percent of Total
Source&Random	0.002889	39.978
Residual	0.004337	60.022
Total	0.007226	100.000

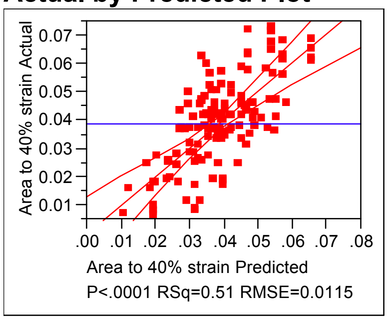
Prediction Profiler



Appendix 5d
Regression Analysis of Area to 40% Strain for Parallel Orientation

Outliers deleted

Response Area to 40% strain
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.506816
RSquare Adj	0.479197
Root Mean Square Error	0.011482
Mean of Response	0.038844
Observations	133

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.01693454	0.002419	18.3507
Error	125	0.01647908	0.000132	Prob > F
C. Total	132	0.03341362		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0798168	0.004502	17.73	<.0001
Temp	-0.000174	0.000023	-7.63	<.0001
Humidity	-0.000258	0.000032	-8.14	<.0001
Duration (week)	-0.00051	0.000136	-3.75	0.0003

w/Random Sample Source Terms

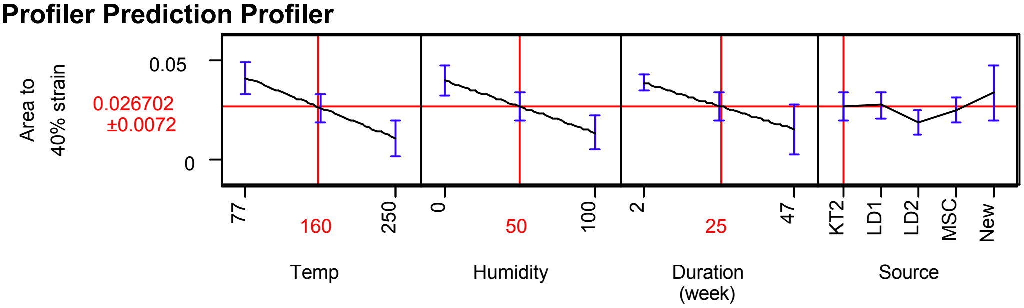
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Source&Random	0.000013	9.155
Residual	0.000132	90.845
Total	0.000145	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp	0.00767	0.00767	1	58.1952	<.0001
Humidity	0.00874	0.00874	1	66.2943	<.0001
Duration (week)	0.00186	0.00186	1	14.0892	0.0003
Source&Random	0.00177	0.00044	4	3.3471	0.0122

Profiler Prediction Profiler



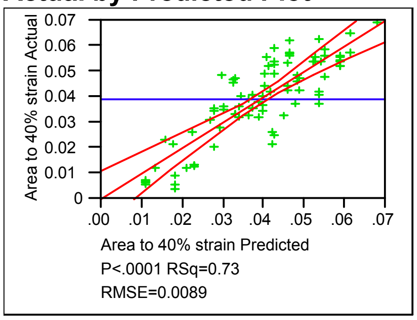
Appendix 5e
Regression Analysis of Area to 40% Strain for Perpendicular Orientation

Outliers deleted

Response Area to 40% strain

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.727422
RSquare Adj	0.702642
Root Mean Square Error	0.008899
Mean of Response	0.039177
Observations	85

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.01627191	0.002325	29.3554
Error	77	0.00609739	0.000079	Prob > F
C. Total	84	0.02236930		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0710152	0.004169	17.03	<.0001
Temp	-0.000104	0.000021	-4.91	<.0001
Humidity	-0.000357	0.00003	-11.97	<.0001
Duration (week)	-0.000455	0.00011	-4.13	<.0001

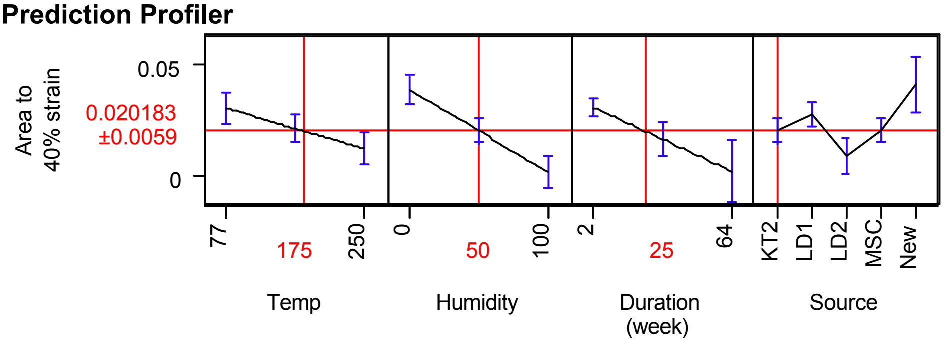
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Source&Random	0.000056	41.282
Residual	0.000079	58.718
Total	0.000135	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Temp	0.00191	0.00191	1	24.0624	<.0001
Humidity	0.01135	0.01135	1	143.3714	<.0001
Duration (week)	0.00135	0.00135	1	17.0200	<.0001
Source&Random	0.00322	0.0008	4	10.1542	<.0001

Prediction Profiler



Appendix 6a
Regression Analysis of Density Loss at Low Temp when Humidity=0% Material Source=MSC (97% of the Mass Loss Samples)

Deleted all Time=0 Records
Fraction Density Loss: 1- (Density at time t)/(Density at start after Time 0)

Response Fraction Density Loss
Summary of Fit

RSquare	0.411932
RSquare Adj	0.357045
Root Mean Square Error	0.004053
Mean of Response	0.007021
Observations	83

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.00086299	0.000123	7.5052
Error	75	0.00123199	0.000016	Prob > F
C. Total	82	0.00209498		<.0001

Tested against reduced model: Y=mean

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Zeroed	0	0	.	.
Time (days)		0.0000211	0.000004	4.90	<.0001
Temp		0.0000715	0.000019	3.72	0.0004

w/ Random Sample ID's

Variance Component Estimates

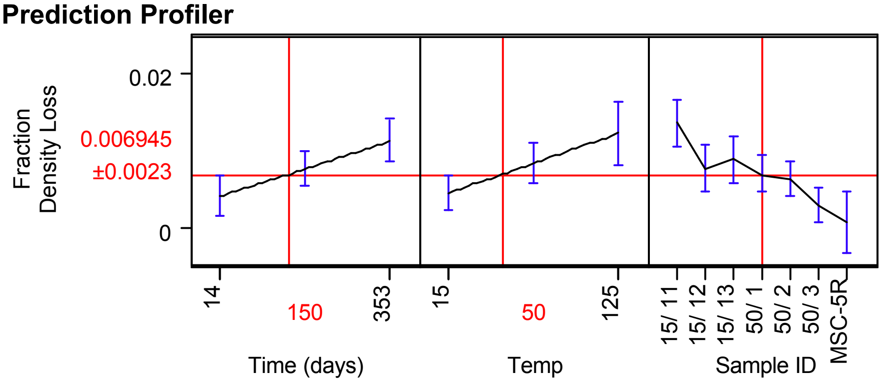
Component	Var Comp Est	Percent of Total
Sample ID&Random	0.000008	33.273
Residual	0.000016	66.727
Total	0.000025	100.000

These estimates based on equating Mean Squares to Expected Value.

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Time (days)	0.00039	0.00039	1	23.9882	<.0001
Temp	0.00023	0.00023	1	13.8433	0.0004
Sample ID&Random	0.00063	0.00011	6	6.4185	<.0001

Prediction Profiler



Appendix 6b
Regression Analysis of Weight Loss at Low Temp when Humidity=0% Material Source=MSC (97% of the Mass Loss Samples)

Response Fraction Weight Loss
Summary of Fit

RSquare	0.818771
RSquare Adj	0.79944
Root Mean Square Error	0.00319
Mean of Response	0.010775
Observations	84

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	0.00344880	0.000431	42.3552
Error	75	0.00076337	0.000010	Prob > F
C. Total	83	0.00421217		<.0001

Tested against reduced model: Y=mean

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Zeroed	0	0	.	.
Time (days)		0.0000225	0.000003	6.58	<.0001
Temp		0.0001301	0.000015	8.60	<.0001
(Time (days)-179.274)*(Temp-39.1071)		-4.314e-7	1.411e-7	-3.06	0.0031
w/ Random Sample ID's					

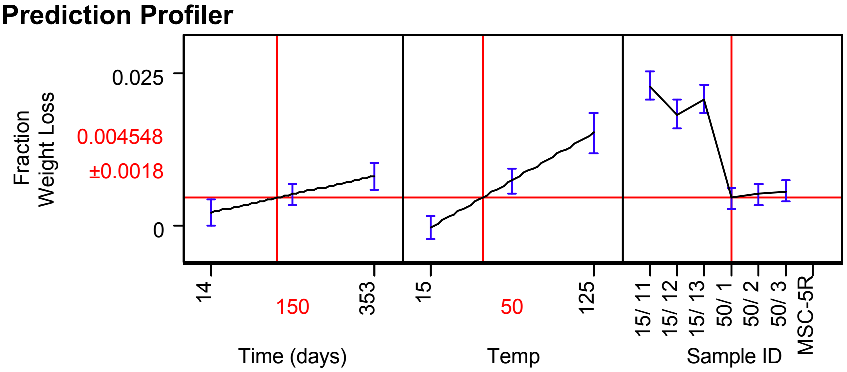
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Sample ID&Random	0.000051	83.231
Residual	0.00001	16.769
Total	0.000061	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Time (days)	0.00044	0.00044	1	43.2833	<.0001
Temp	0.00075	0.00075	1	74.0401	<.0001
Time (days)*Temp	0.0001	0.0001	1	9.3444	0.0031
Sample ID&Random	0.00333	0.00055	6	54.4471	<.0001

Prediction Profiler



Appendix 6c
Regression Analysis of Density Loss at High Temp when Humidity=0% and Material Source=MSC (97% of the Mass Loss Samples)

Response Fraction Density Loss
Summary of Fit

RSquare	0.726123
RSquare Adj	0.722103
Root Mean Square Error	0.005477
Mean of Response	0.009687
Observations	1107

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	16	0.08669949	0.005419	180.6180
Error	1090	0.03270108	0.000030	Prob > F
C. Total	1106	0.11940057		<.0001

Tested against reduced model: Y=mean

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Zeroed	0	0	.	.
Time (days)&RS		0.000075	0.000002	31.26	<.0001
Temp&RS		0.0000142	0.000002	8.28	<.0001
(Time (days)-110.175)*(Temp-215.894)		0.0000017	7.53e-8	22.21	<.0001

w/ Random Sample ID's

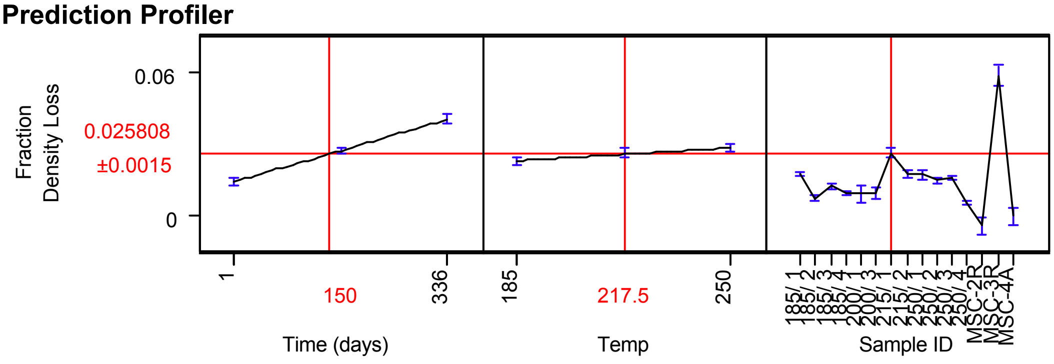
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Sample ID&Random	0.00005	62.403
Residual	0.00003	37.597
Total	0.00008	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Time (days)&RS	0.02932	0.02932	1	977.1863	<.0001
Temp&RS	0.00206	0.00206	1	68.5140	<.0001
Time (days)*Temp	0.0148	0.0148	1	493.3741	<.0001
Sample ID&Random	0.04717	0.00337	14	112.3014	<.0001

Prediction Profiler



Appendix 6d
Regression Analysis of Weight Loss at High Temp when Humidity=0% and Material Source=MSC (97% of the Mass Loss Samples)

Response Fraction Weight Loss
Summary of Fit

RSquare	0.973673
RSquare Adj	0.97329
Root Mean Square Error	0.003297
Mean of Response	0.024349
Observations	1116

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	16	0.44194196	0.027621	2540.326
Error	1099	0.01194960	0.000011	Prob > F
C. Total	1115	0.45389156		0.0000

Tested against reduced model: Y=mean

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept	Zeroed	0	0	.	.
Time (days)&RS		0.0001784	0.000001	124.34	0.0000
Temp&RS		0.0000139	0.000001	13.47	<.0001
(Time (days)-110.194)*(Temp-216.111)		0.0000035	4.497e-8	77.97	0.0000
w/ Random sample ID's					

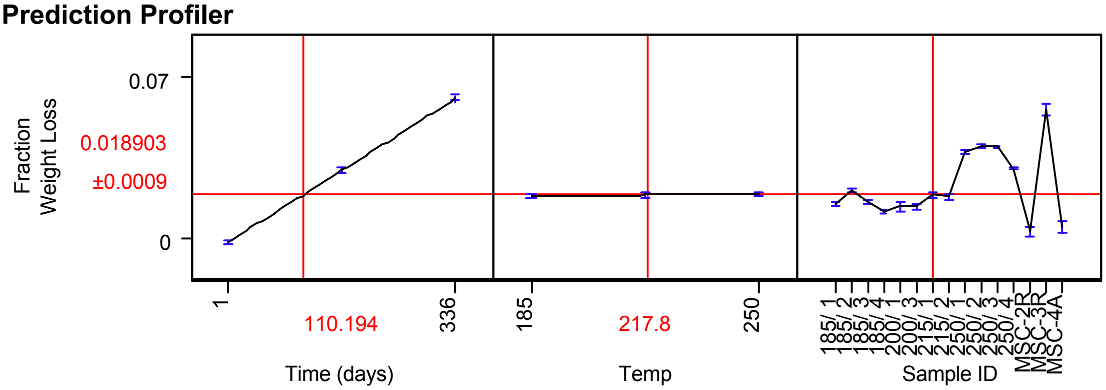
Variance Component Estimates

Component	Var Comp Est	Percent of Total
Sample ID&Random	0.000135	92.533
Residual	0.000011	7.467
Total	0.000146	100.000

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Time (days)&RS	0.1681	0.1681	1	15460.1	0.0000
Temp&RS	0.00197	0.00197	1	181.3492	<.0001
Time (days)*Temp	0.0661	0.0661	1	6079.009	0.0000
Sample ID&Random	0.12765	0.00912	14	838.5867	0.0000

Prediction Profiler



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