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COMPACTION OF FIBERBOARD OVERPACK MATERIALS IN A 9975 SHIPPING PACKAGE

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ABSTRACT

Compaction of lower layers in the 9975 fiberboard overpack has been observed in packages that contain excess moisture. Dynamic loading of the package during transportation may also contribute to compaction of the fiberboard. This condition is being tested and analyzed to better understand these compaction mechanisms and provide a basis from which to evaluate their impact to the safety basis for transportation (Safety Analysis Report for Packaging) and storage (facility Design Safety Analysis) at the Savannah River Site (SRS). A test program has been developed and is being implemented to identify the extent of the compaction as a function of fiberboard moisture and typical transport dynamic loadings. Test conditions will be compared to regulatory requirements for dynamic loading. Characterization of the recovery of short-term compaction following the application of dynamic loading is also being evaluated. Interim results from this test program will be summarized.

INTRODUCTION

The Savannah River Site (SRS) stores packages containing plutonium (Pu) materials in the K-Area Materials Storage (KAMS) facility. The Pu materials are packaged per the DOE 3013 standard and stored within 9975 packages in KAMS [1]. The 9975 is a certified radioactive material shipping package designed and sponsored by the Savannah River National Laboratory (SRNL).

The facility DSA (Document Safety Analysis) [2] credits the 9975 package to perform several safety functions, including criticality control, impact resistance, containment, and fire resistance to ensure the plutonium materials remain in a safe configuration during normal and accident conditions. In the storage facility, the 9975 package is assumed to perform its safety function for at least 12 years from initial packaging. Celotex® cane- or softwood-based fiberboard is used as overpack material in the 9975 (Figure 1) and supports the fire resistance, criticality control, and impact resistance functions.

The DSA recognizes the degradation potential for the materials of package construction over time in the KAMS storage environment and requires an assessment of materials performance to validate the assumptions of the analysis and ultimately predict service life and the need for repackaging. One of the parameters used to monitor the fiberboard condition is the axial gap between the drum flange and the top of the fiberboard assembly. Recent experience includes the identification of several packages in which this gap has increased and exceeded the response threshold of 1 inch. This observation was generally accompanied by elevated moisture levels in the bottom fiberboard layers and compaction of those layers. Elevated moisture might accumulate within the fiberboard from the introduction of additional moisture to the package, or by the concentration of existing moisture into local regions through migration under thermal gradient.

The impact of elevated moisture on fiberboard properties and the response of the package to changing moisture conditions has been recently described [3]. Over time, elevated moisture levels will enhance the degradation rates of the fiberboard properties [4, 5]. With the recent identification of several 9975 packages with an axial gap greater than one inch, and possible association of that criterion to the fiberboard condition, this paper will describe efforts to help understand the relationship between fiberboard moisture level and compaction of the lower layers.

The bottom of the 9975 outer drum is dished, and the fiberboard overpack is fabricated with a flat bottom. Therefore, as the load on the fiberboard increases, the bottom layer will increasingly compress from the outer edge inward as it conforms to the drum bottom. The lead shield (and the containment vessels and payload it contains) sit on an aluminum bearing plate embedded within the lower fiberboard assembly. With no payload, the shield, containment vessels and a typical 3013 container place a load of approximately 119 kg (263 pounds) on the 28 cm (11.2 inch) diameter bearing plate.

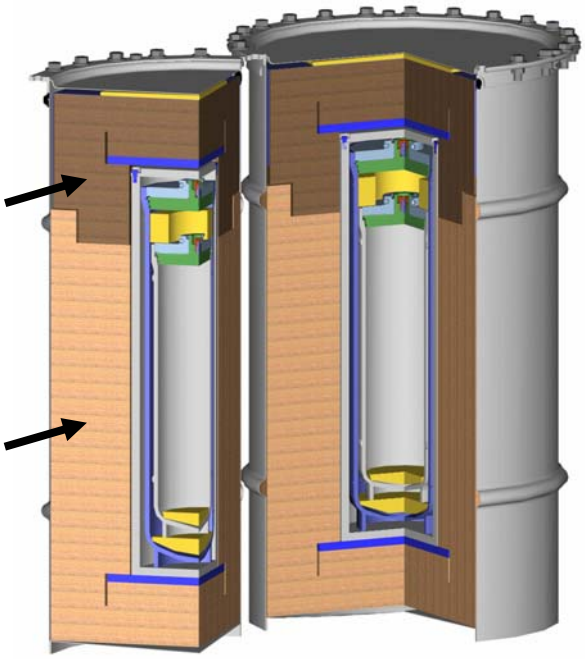


Figure 1. Cross section of the 9975 shipping package showing the configuration of the of the fiberboard overpack. The upper and lower fiberboard assemblies are indicated (arrows).

Typically, a compressed ring approximately 4 - 5 cm (1½ - 2 inches) wide will form around the bottom surface. As the bottom layer(s) compress further (due to increased loading or reduced fiberboard strength), this ring will widen until the entire fiberboard bottom surface is in contact with the drum bottom. This has been observed in packages with elevated moisture content, and is illustrated in Figure 2. With the limited contact area, the local stress in the bottom fiberboard layers is typically no greater than 23 kPa (3.4 psi). As the compressed region widens, the local peak stress decreases to 18 kPa (2.7 psi), which is the stress immediately under the bearing plate.

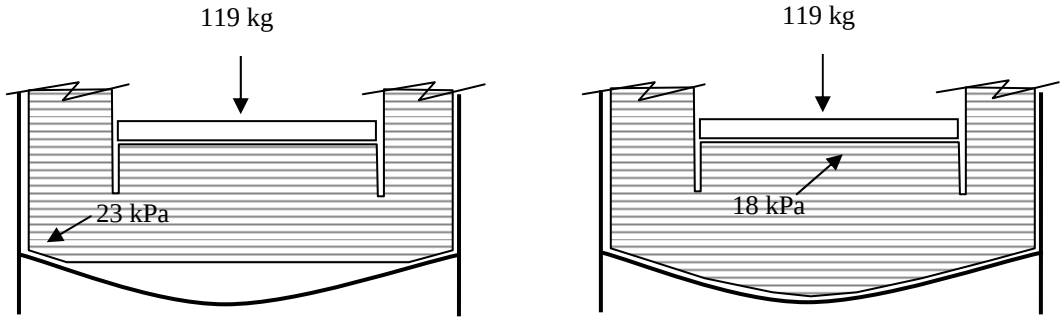


Figure 2. Varying degree of contact between the lower fiberboard assembly and drum bottom. As the contact increases, the peak fiberboard stress will decrease to that immediately under the bearing plate.

TEST METHODOLOGY

The impact of fiberboard moisture level on compaction under load is being analyzed using three test methods. Each method reflects the response of fiberboard to transient loadings on a different time scale. Short-term testing measures the fiberboard response under load within a single, very long load cycle. Dynamic testing subjects samples to a dynamic load of varying frequency and magnitude, such as might occur during handling and transport. An intermediate time scale is seen in standard compression test data, which subjects the sample to a single half-cycle loading event. While the dynamic testing best represents the conditions a package might experience in service, the other methods offer a simpler look at the basic response of the fiberboard under load.

Short-Term Testing Samples are approximately 4 x 4 x 2.2 inches (10 x 10 x 5.6 cm) in size, and were removed from the same fiberboard assembly. Each sample has different moisture content, ranging from approximately 10 to 35 %WME (wood moisture equivalent). (%WME represents the electrical resistivity measured by a wood moisture meter. For cane fiberboard, it relates to moisture content by: wt% moisture ≅ 0.67 * %WME + 2.6, over a range up to ~40 %WME.) Each sample is contained within a plastic bag to help maintain a constant moisture level throughout testing. For nominal moisture samples (10 - 15 %WME), the target stress level is approximately 3.4 psi. For higher moisture content (≥ 20 %WME), the target stress level is approximately 2.7 psi. These stress levels are achieved by placing a weight on each sample (see Figure 3).

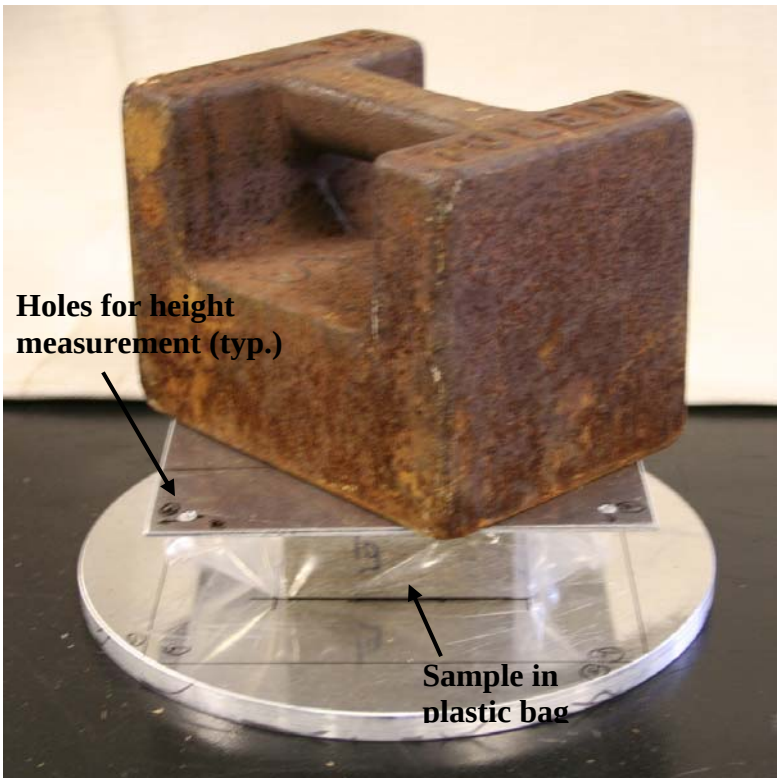


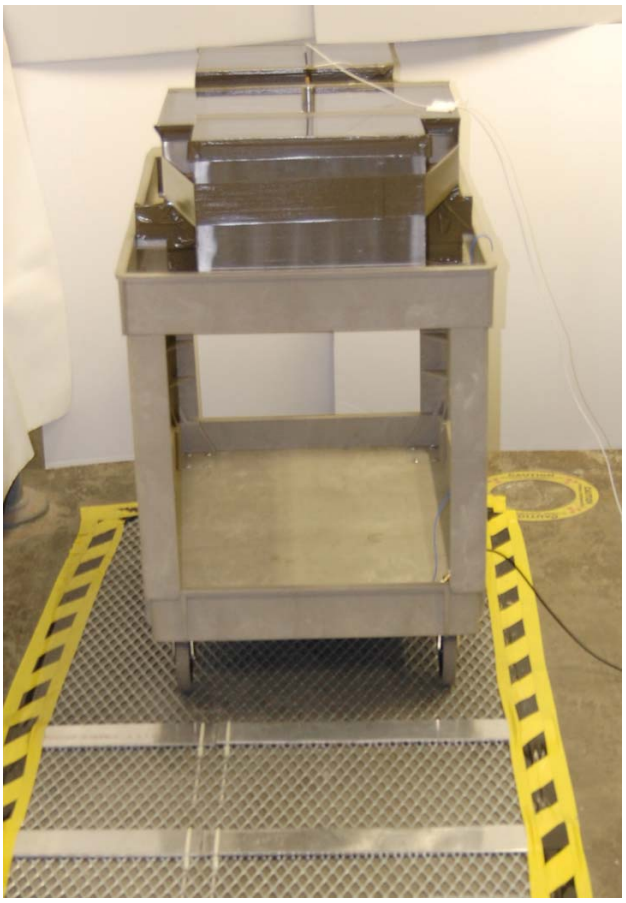
Figure 3. Typical test setup for short-term test sample. Sample height is measured in-situ by extending a calipers through each of 4 holes in the upper plate.

The initial load is placed on each sample, and the sample height allowed to stabilize. The degree of compression is checked periodically. The load on each sample is then doubled to simulate one very slow cycle of dynamic loading. Each load is then removed in steps as the material rebound is measured.

Dynamic Testing: Two sets of fiberboard samples are placed under load similar to that seen in service by the lower layers in a 9975 package, and compactions are tracked over time. One set is subjected to periodic dynamic loading that simulates potential transport conditions. The second control set experiences a static load only. Sample height and moisture content are recorded periodically.

Samples are the same size as for short-term testing, and were removed from the same fiberboard assembly. Each set consists of three samples that contain moisture levels of approximately 10, 20 and 30 %WME. Each sample is enclosed within a box to help maintain a constant moisture level throughout testing. The target stress level for each sample is the same as described above. These stress levels are achieved by placing a weight on each sample. The three dynamic samples are secured to a cart, and the dynamic loadings result as the cart is moved over a rough surface (metal plates mounted to an expanded metal sheet) according to a set pattern (see Figure 4). The degree of sample compression is checked after each transport cycle simulation.

The dynamic load transmitted to the samples by rolling a cart over a rough surface is recorded using accelerometers. One accelerometer (PCB model #353B33, Sensitivity=0.104 Volt/g) is screw mounted to the top of the sample enclosure, and a second accelerometer (Kistler model #8630B5, Sensitivity=0.984 Volt/g) is mounted with wax adhesive to the floor of the cart proximate to a corner. Initial efforts to use an accelerometer with greater sensitivity were unsuccessful due to saturation of the sensing element from the impulsive loads experienced by the cart.



(a) Sample boxes on cart

(b) Arrangement within sample boxes

Figure 4. Test setup of the dynamic load test for samples at 10, 20, and 30 %WME.

Compression Testing

A set of 8 compression samples (~2 x 2 x 2 inch) were tested with the load applied perpendicular to the fiberboard layers, with a crosshead speed of 1.9 inch/minute. The samples were taken from 3 different package assemblies, and had moisture content ranging from 6.7 to 12.7 %WME, which is typical of the seasonal variation for material in equilibrium with the ambient humidity. One additional sample from the same package used for the other tests (2028) was also tested with a moisture content of 10.9 %WME, to provide a direct comparison to results from the other test methods.

The compression test behavior of fiberboard has been described previously [5, 6]. While a compression test typically extends to high strain levels, the data of current interest is the compression behavior at very low strains, corresponding to stress levels of < 10 psi.

RESULTS

Short-Term Testing

The short-term samples were maintained under load for varying periods, depending on the sample response. The change in sample height during loading and unloading for samples with 10 and 30 %WME is shown in Figures 5 and 6, respectively.

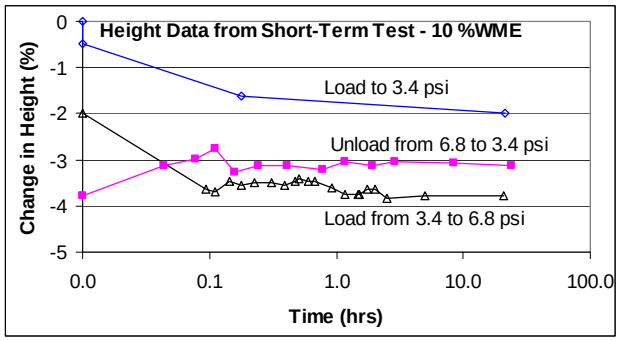


Figure 5. Change in sample height during short-term testing for 10 %WME.

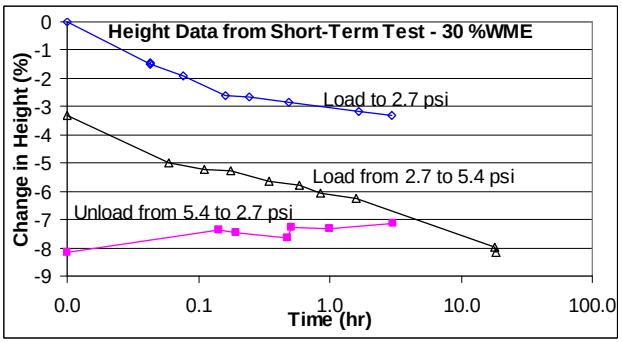


Figure 6. Change in sample height during short-term testing for 30 %WME.

Dynamic Testing

The dynamic samples were subjected to dynamic transport simulation cycle immediately after they were placed under nominal load, and again after 1 week. Sample heights were measured before and after each cycle. The control samples were measured weekly. The relative change in height for each of these samples is shown in Figure 7. Limited duration data are available at present for the dynamic test samples. Additional data will be collected in the future.

During the transport simulation cycle, acceleration data was recorded in 2 second intervals over a frequency range of 0-100 Hertz. The dynamic data was captured using a Fast Fourier Transform (FFT) analyzer, in a continuous capture mode, to collect all data while the cart was rolled over the rough surface. The FFT analyzer was configured with measurement parameters that included a 0-100 Hertz frequency range, Peak Continuous capture mode (i.e., the peak value measured at each frequency is retained and updated for each increment of the overall measurement), and Hanning Window data clipping to improve measurement accuracy by minimizing FFT leakage resulting from waveform time-to-frequency domain transformation.

In Figures 8 and 9, "Chan 1" corresponds to output from the sample enclosure mounted accelerometer, and "Chan 2" is for the cart floor-mounted accelerometer. "Inst Time" in Figure 8 is a 2 second interval of the recorded acceleration response for the two accelerometer locations. The "Power Spectrum" in Figure 9 shows the acceleration maximum measured for each frequency in the 0-100 Hertz range. The "Avg=25" in the plot indicates that 25 two second intervals were collected to obtain the displayed data.

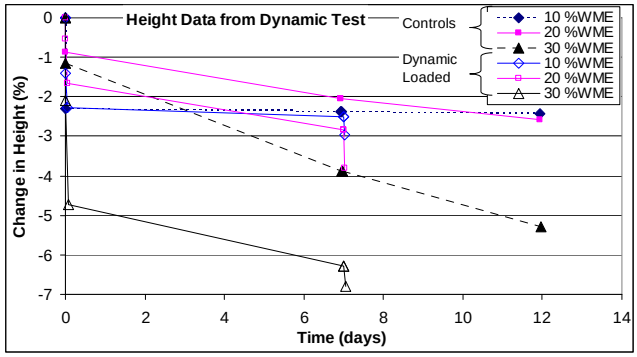


Figure 7. Relative change in height under load for dynamic test samples. The 10 %WME samples were loaded to 3.4 psi, while the other samples were loaded to 2.7 psi.

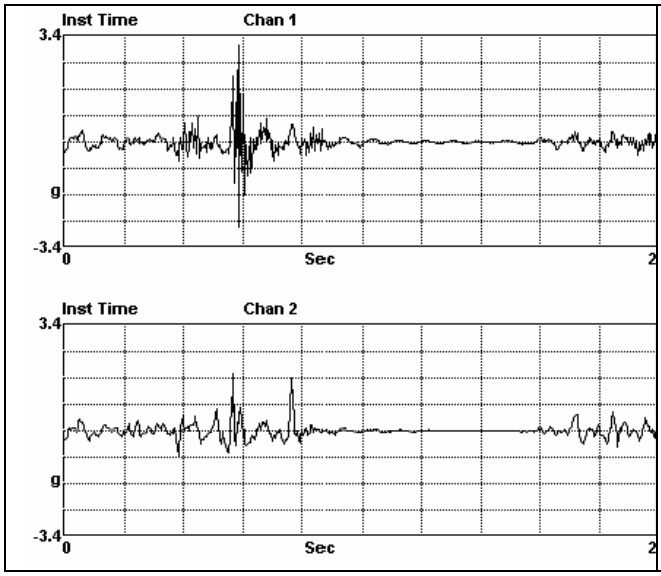


Figure 8 Two second interval of the recorded acceleration response for the two accelerometer locations. The Channel 1 accelerometer is mounted on the sample enclosure. The Channel 2 accelerometer is mounted on the cart floor.

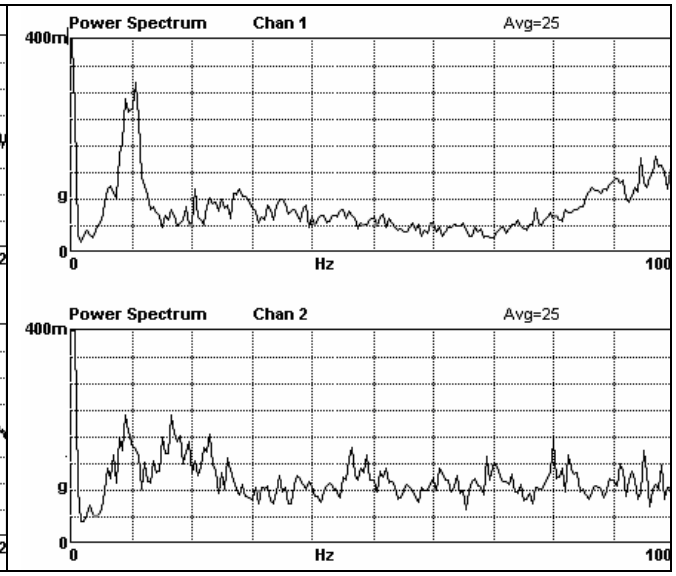


Figure 9 Acceleration maximum measured for each frequency in the 0 – 100 Hz range, based on 25 two second intervals. The Channel 1 accelerometer is mounted on the sample enclosure. The Channel 2 accelerometer is mounted on the cart floor.

Compression

A range of stress-strain response is seen based on the source package and moisture content (Figure 10). This figure shows package-to-package variation in addition to variation from moisture content.

The area of interest in the compression test curve is at very low stress levels (~3 – 5 psi). However, the stress-strain curve is not always consistent in this range due to minor sample misalignment, machine slack, etc. Therefore, the behavior at this stress level is determined by measuring the slope of the stress-strain curve at higher stress levels and extrapolating to lower stresses. This is illustrated in Figure 11 for the LD2 package samples. The slope for each sample is summarized in Table 1 along with the extrapolated degree of compression at stresses of 3.4 and 6.8 psi.

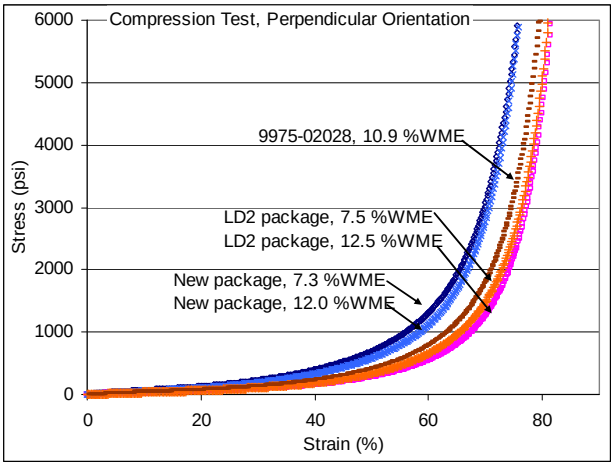


Figure 10 Stress strain curves for fiberboard from two packages at two moisture levels, compared to package 9975-02028.

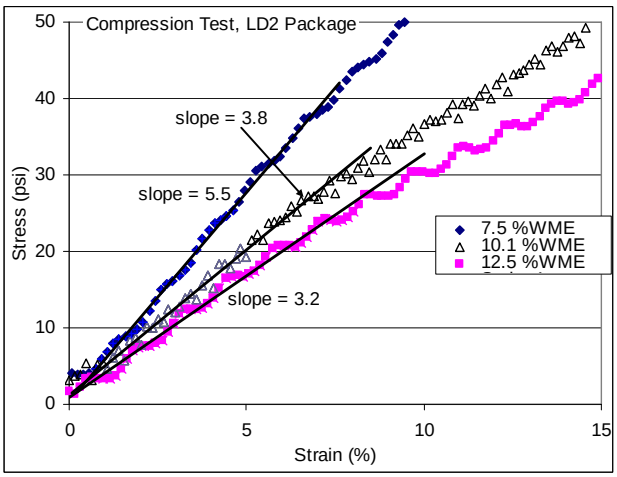


Figure 11 Low stress portion of compression test curves for LD2 package samples, with slope fit to lower section of the curve.

Table 1. Summary of slopes from low stress portion of compression test curves, with extrapolated estimates of compression (percentage loss of original height) at select stress levels.

	Package LD1	Package LD2	Package New	9975-02028
Slope of compression curve @ moisture level			7.5 psi/% @ 6.7 %WME	
	5.5 psi/% @ 7.9 %WME	5.5 psi/% @ 7.5 %WME	8.7psi/% @ 7.3 %WME	
		3.8 psi/% @ 10.1 %WME		4.9 psi/% @10.9 %WME
	3.9 psi/% @ 12.7 %WME	3.2 psi/% @ 12.5 %WME	7.5 psi/% @ 12.0 %WME	
Estimated sample compression at 3.4 psi	0.62% @ 7.9 %WME	0.62% @ 7.5 %WME	0.39% @ 7.3 %WME	
	0.87% @ 12.7 %WME	1.06% @ 12.5 %WME	0.45% @ 12.0 %WME	0.69% @10.9 %WME
	Package LD1	Package LD2	Package New	9975-02028

Estimated sample compression at 6.8 psi	1.24% @ 7.9 %WME	1.24% @ 7.5 %WME	0.78% @ 7.3 %WME	
	1.74% @ 12.7 %WME	2.12% @ 12.5 %WME	0.91% @ 12.0 %WME	1.39% @10.9 %WME

DISCUSSION

The safety analysis for the 9975 package includes discussion of the vibration from road transportation loadings [7]. These are bounded by a high amplitude low frequency envelope of 1 – 1.5g at 2 – 7 Hz. This envelope would provide a conservative bound to typical vibrations on a smooth road. Similar loadings might be postulated to result from handling the drums within a facility. In contrast, the vibratory loadings measured during dynamic testing are much smaller in amplitude.

Examination of Figures 4 and 5 shows slightly higher acceleration values in both "Inst Time" and "Power Spectrum" plots for the accelerometer mounted on the sample enclosure. This result is expected as the hard plastic enclosure has additional flexibility which amplifies the input acceleration. Since multiple sample enclosures are placed on the cart for dynamic loading, the dynamic acceleration imparted to each sample from the cart floor would be slightly different, but bounded by the "Chan 1" and "Chan 2" data.

The power spectrum for "Chan 2" is considered typical for the sample dynamic loading. The data from this spectrum indicates a fairly uniform acceleration input of ~0.1g in the 5-100 Hertz frequency range. Excitation in the 0-5 Hertz range is low, as expected, due to the hardness of the cart wheels and steel expanded metal surface. Since the mass mounted on the top of each sample is rigid, the dynamic force experienced by the sample would be equivalent to 0.1g multiplied by the weight of the compressing object, applied as a sinusoidal load over a duration equal to time spent rolling the cart over the rough surface.

In the short-term tests, the initial loading cycle (to 2.7 or 3.4 psi) is indicative of the response of the lower layers of the fiberboard assembly when the package is first assembled. Similarly, the second loading cycle (5.4 or 6.8 psi) might approximate the response during some period of handling or transport, and removal of the higher load represents an end to the dynamic activity as the package sits in storage. Further insight into the actual behavior during transport would come from the results of the dynamic testing.

Under conditions typical of many packages (~10 %WME, 3.4 psi stress) both the short term and dynamic samples show about 2% strain (reduction in height). Under a static stress of 6.8 psi (essentially a single cycle 1g load input), the short term sample experienced additional compression of ~2%. Under dynamic loading, there was little additional strain at this moisture level. This difference from the short term sample results from the lower magnitude of dynamic loading (~0.1 g for the dynamic sample, ~1g for the static sample). However, additional replications of the simulated transport cycle would be expected to produce further compression. In comparison to these results, the compression test sample experienced less strain at 3.4 psi (~0.7%). This likely results from the immediate measurement of sample displacement rather than allowing the sample to settle for a short period before measuring the height.

At a higher moisture level, the behavior varies somewhat. The strains are higher with the increased moisture level, and strain continues to increase for a longer period of time. This behavior is seen in

all samples (dynamic, dynamic control and short term). However, the rate of compression of the dynamic sample while between dynamic cycles is less than the rate of compression of the control sample.

As each of the short term samples is unloaded, there is some recovery of sample height, but some compression set remains.

The compression test data indicates a degree of variation in behavior between different packages. This is consistent with observation of other fiberboard properties [6] Similar variation would be expected in the response to dynamic loading. The degree of compression predicted by the compression test data for a given stress is less than measured in the dynamic and short term samples. Therefore, while the compression test is a common and convenient way to measure the mechanical response of the fiberboard, it is non-conservative in this application.

CONCLUSIONS

Higher moisture levels and dynamic loading contribute to the compaction of the fiberboard. At lower levels of moisture (10 – 15 %WME) both the short term and dynamic samples show about 2% strain (reduction in height). When the static stress of the samples was increased, the short term samples experienced an additional compression of ~2%, while the dynamic samples experienced little additional strain at this moisture level. At higher moisture levels, although the response is not as uniform, the strains are higher and continue to increase for a longer period of time. This behavior is seen in all samples (dynamic, dynamic control and short-term). However, the rate of compression of the dynamic samples between dynamic cycles is less than the rate of compression of the control samples. As the load is removed from each of the short term samples, there is some recovery of sample height, but some compression set remains.

Additional testing is needed to further understand the relationship between the fiberboard moisture level and compaction of the lower fiberboard assembly. Further insight into the actual behavior during transport will come from the results of the dynamic testing.

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