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EXAMINATION OF SR101 SHIPPING PACKAGES

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Summary

Four SR101 shipping packages were removed from service and provided for disassembly and examination of the internal fiberboard assemblies. These packages were 20 years old, and had experienced varying levels of degradation. Two of the packages were successfully disassembled and fiberboard samples were removed from these packages and tested. Mechanical and thermal property values are generally comparable to or higher than baseline values measured on fiberboard from 9975 packages, which differs primarily in the specified density range. While baseline data for the SR101 material is not available, this comparison with 9975 material suggests that the material properties of the SR101 fiberboard have not significantly degraded.

Background

On October 23, 2014, four SR101 shipping packages (serial numbers 2, 29, 39 and 42) were opened and examined. SRNL/Materials Science & Technology (Daugherty) participated in this effort at the request of SRNL/Packaging Technology & Pressurized Systems (Blanton), with the goal of identifying the condition of the internal fiberboard assembly. The High Pressure Lab (Holiday) also participated in the effort. Three of these four packages (29, 39 and 42) were fabricated in 1994 under PO# AB40318A [1] and are approximately 20 years old. Package 2 was fabricated under a different PO and is likely of a similar age. However, its history was not checked since it was not successfully disassembled. All four packages were removed from service because they had sustained varying degrees of wear which prevented their continued use without repair.

The fiberboard in the initial package design was specified as cane fiberboard meeting ASTM C208-72 roof insulating board, with a density of 15-18 lb/cu ft [2]. Starting in Revision 3 of this drawing, the fiberboard specification was changed to ASTM C208-95, and the product type was changed to wall sheathing, regular grade (Type IV, Grade 1) with a density of 14-16 lb/cu ft. The individual fiberboard layers are ½ inch thick, and are laminated together up to 4 layers thick with Type M adhesive. Each layer has a black coating, described in Knight-Celotex literature as intended to reduce asphalt bitumen absorption. These laminations are joined by 4 threaded rods that pass through the full height of the fiberboard assembly. All exposed fiberboard surfaces are coated with vinyl acrylic master weather coating (mastic) [2].

During disassembly, visual observations were made, along with dimensional measurements of the fiberboard. Sections were later removed from 2 fiberboard assemblies for additional testing.

Examination and Test Results

Photographs of each package were taken during disassembly. Figures 1-6 show typical packaging assemblies and some of the damage that was encountered during disassembly and examination. Additional photographs of each package were taken and were provided to SRNL/Packaging Technology & Pressurized Systems (Blanton). The upper fiberboard plug assembly is a combination of a fiberboard disc, and foam discs. The components of this plug were separated and/or broken in packages 29 and 39 (Figure 2). A range of conditions was observed for the lower fiberboard assembly in each package. Figure 3 shows an intact lower fiberboard assembly in package 29, and an assembly with the upper layers detached in package 2.

The lower fiberboard assembly was very tight in the drum for all 4 packages. When removal by inverting the drum was unsuccessful, removal was attempted by driving two steel hooks into the lower assembly below the steel ring to provide a grip on the fiberboard (Figure 4). This approach was successful in removing the fiberboard from packages 39 and 42, but not the other two packages. In packages 2 and 42, the upper ring of the lower fiberboard assembly was broken off (Figures 4 - 6).

Several fiberboard dimensions were measured and recorded, as documented and illustrated in Table 1. Also shown in Table 1 are the nominal values for these dimensions. Several dimensions were not recorded as noted, but the recorded values are reasonably consistent with the nominal values.

Subsequent to the disassembly efforts, sections were removed from the lower fiberboard assemblies for packages 39 and 42 (the two assemblies that were removed from their drum). These sections were not identified with the package from which they were removed, so they were subsequently identified as A and B. From each of these sections, samples were machined for compression, thermal conductivity and specific heat capacity tests.

Compression samples, approximately 2.2 x 2.2 x 2.4 inch (the larger dimension is the actual full radial thickness of the assembly), were tested with the applied load either parallel or perpendicular to the fiberboard layers. Most of the samples were tested with the coating intact on the OD and ID faces, but a few were tested with the coating removed, for comparison. Testing was performed at room temperature, with a crosshead speed of 1.9 inch/minute. Two metrics are used to compare the mechanical behavior of the fiberboard. Of importance to accident scenarios is the energy absorption capacity, which can be represented by the area under the stress-strain curve up to a strain of 40%. The second metric is the buckling strength (applicable to parallel orientation samples).

Compression samples are shown in Figures 7-9. Stress-strain curves are provided in Figures 10 and 11. Figures 12 and 13 show photo sequences of several of the parallel orientation samples during testing. Test metrics are summarized in Figures 10 and 11.

Thermal conductivity samples are typically about 7 x 7 x 1.4 inch (Figures 14 and 15). Thermal conductivity is measured using a Lasercomp Fox 300 instrument at mean test temperatures of 25, 50 and 85ºC. This instrument provides results consistent with ASTM C518. One sample was prepared from each of the two assemblies. Due to the limiting wall thickness, the samples were oriented to measure thermal conductivity in the radial direction only. Results are summarized in Table 3.

Specific heat capacity samples are approximately 1 inch diameter and 1.5 inch high (Figure 16). This testing is performed in accordance with ASTM C351 at mean test temperatures of 25 and 51ºC. Consistent with the ASTM procedure, one or more trials is performed on each of several samples, with all trials averaged for a single result. Averaging over multiple trials significantly reduces the scatter from individual trials. The average specific heat capacity calculated for a mean temperature of 25ºC, based on 3 trials, is 1209 ± 157 J/kg-K. The average specific heat capacity calculated for a mean temperature of 51ºC, based on 9 trials, is 1342 ± 101 J/kg-K. More trials were performed at 51ºC, and this result is preferred for use, since the test can be performed with greater consistency at this temperature.

Discussion

The density of the fiberboard used in these packages is specified as 15 – 18 lb/cu ft. For the 8 compression samples which retained the glue and black coating on each layer and mastic coating, the average density is 23 lb/cu ft. For the remaining compression samples and thermal conductivity samples (which contained glue and black coating on each layer but no mastic coating), the average density is 22 lb/cu ft. Two leftover fiberboard sections were cut apart and had the glue and black surface coating removed from each fiberboard layer. When this remaining material was re-stacked and measured, the average density was 20 lb/cu ft. Moisture absorption is probably not a significant contributor to an increased density since all the SR101 samples were relatively dry (< 6 % wood moisture equivalent, or WME, which is the lower limit that the moisture meter will register).

The fiberboard in the SR101 packages can be compared to that used in 9975 packages, for which significant aging data exist. Fiberboard for the 9975 packages is specified as wall sheathing with a density of 14 – 16 lb/cu ft, otherwise, the specification requirements are the same. Compression data for 9975 fiberboard samples are included in Figures 10 and 11 for comparison. These samples show the typical range for baseline properties. The SR101 samples tested in the perpendicular orientation have higher energy absorption than the 9975 sample range, probably due to the higher density. In the parallel orientation, the SR101 energy absorption values fall within the range of 9975 samples, except for the samples with the coating removed which had lower energy absorption. It was observed that the fiberboard layers in compression samples A5 and B5 (with the coating removed from the front and back faces) were more likely to separate and therefore carry less load.

The thermal conductivity values measured for the SR101 samples are consistent with baseline measurements on 9975 samples, although they are near the upper end of the range for 9975 samples. Fiberboard thermal conductivity would be expected to increase as density increases, and increase as moisture content increases. Since the SR101 fiberboard has higher density and lower moisture content than 9975 fiberboard, similar thermal conductivity values are not unexpected. The specific heat capacity values measured for the SR101 samples fall within the range measured for fiberboard in 9975 packages.

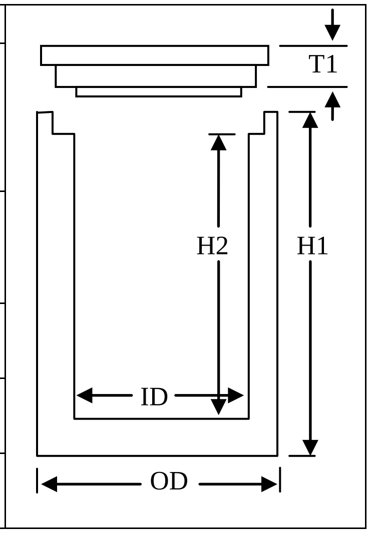
The moisture content of the fiberboard in the SR101 packages is low (< 6 %WME) compared to typical values for the fiberboard in 9975 packages (~8 – 15 %WME). Since the coating on the SR101 assemblies would tend to minimize moisture exchange, it is likely that the low moisture levels have been maintained for the life of the packages. This would greatly contribute to maintaining the fiberboard properties without significant degradation. It is concluded that the fiberboard from packages 39 and 42 has probably not experienced significant degradation in properties, although the fiberboard assemblies had suffered some degree of physical degradation (breakage, wear and tear, etc.).

References

1. Westinghouse Savannah River Company Procurement Quality Assurance – Receiving Inspection Report 94-RIR-16-AB40318A, March 24, 1994
2. Drawing R-R2-H-0009, "Inert Reservoir Packaging (SR-101) Fiberboard Assembly and Details", Rev. 0, September 29, 1993

Table 1. Measured fiberboard dimensions

Dimension	Pkg 2	Pkg 29	Pkg 39	Pkg 42
T1 (3" nom)	3.038 2.969 3.078 3.030	2.946 2.938 2.968 2.972	2.944 2.938 2.948 2.936	2.942 2.916 2.947 2.953
H1 (25.25" nom)	*	*	25.161 25.228	NA – upper ring broken
H2 (21.25" nom)	*	*	21.174 21.098	21.178 21.176
OD (18.12" nom)	*	*	18.157 18.140	18.161 18.169
ID (13.25" nom)	*	*	13.202 13.234	13.218 13.198



* These dimensions were not measured since the bottom fiberboard assembly could not be removed intact from the drum.

Table 2. Physical measurements and density for fiberboard samples

Sample ID	Weight (g)	Length (inch)	Width (inch)	Height (inch)	Density (lb/ft^3)
Compression samples					
A-1 *	71.019	2.204	2.474	2.202	22.5 *
A-2 *	73.354	2.204	2.450	2.201	23.5 *
A-3 *	72.605	2.206	2.480	2.200	23.0 *
A-4 *	74.695	2.205	2.474	2.197	23.7 *
A-5	64.248	2.204	2.288	2.200	22.1
B-1 *	72.554	2.206	2.474	2.197	23.1 *
B-2 *	71.769	2.201	2.485	2.201	22.7 *
B-3 *	72.329	2.202	2.457	2.209	23.1 *
B-4 *	69.889	2.196	2.474	2.201	22.3 *
B-5	61.006	2.209	2.245	2.208	21.2
B-6	63.586	2.212	2.324	2.171	21.7
Thermal conductivity samples					
SR101 A	418	7.057	7.084	1.398	22.8
SR101 B	404	7.071	7.032	1.430	21.6

* These samples retained the coating on the original ID and OD surfaces.

Table 3. Thermal conductivity results

Sample	Thermal conductivity (W/m-K) at a mean temperature of		
	25 C	50 C	85 C
SR101 A	0.1210	0.1232	0.1225
SR101 B	0.1138	0.1187	0.1200
Typ 9975 samples	0.085 – 0.119	0.090 - 0.124	0.094 - 0.127

Figure 1. Top and bottom views of upper plug assembly (package 42).

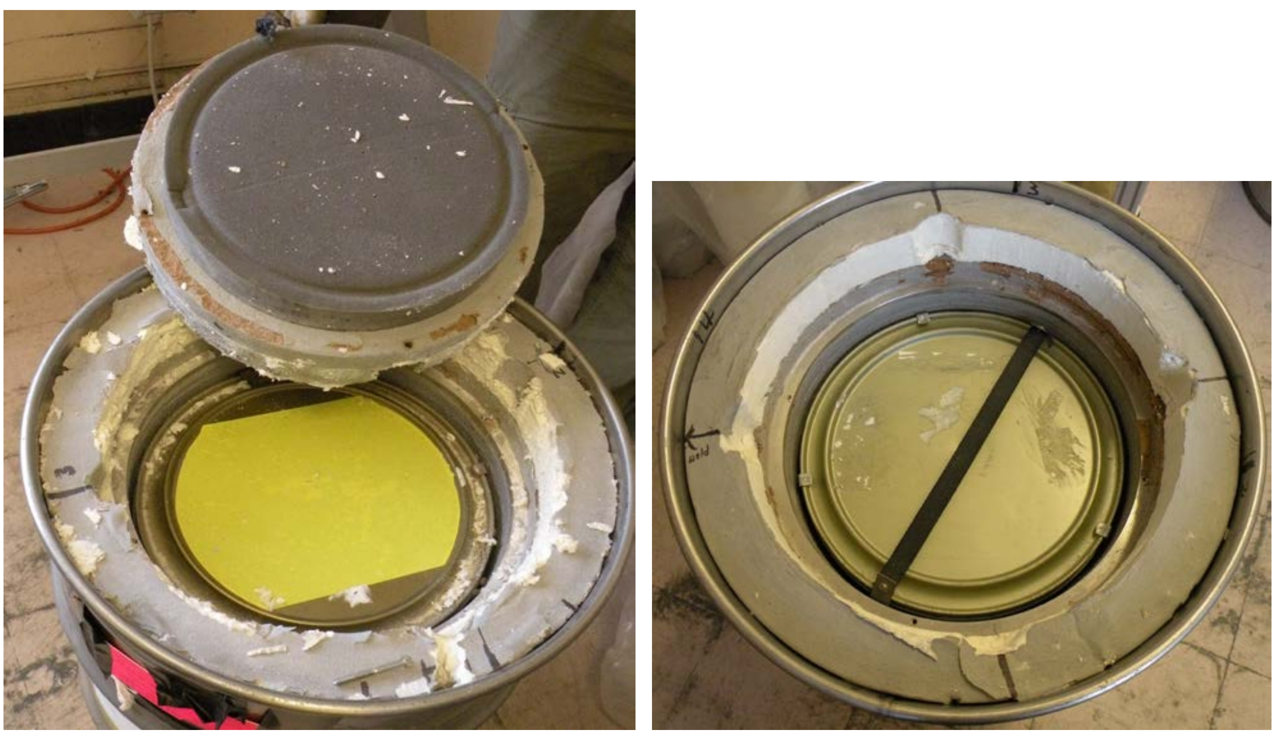


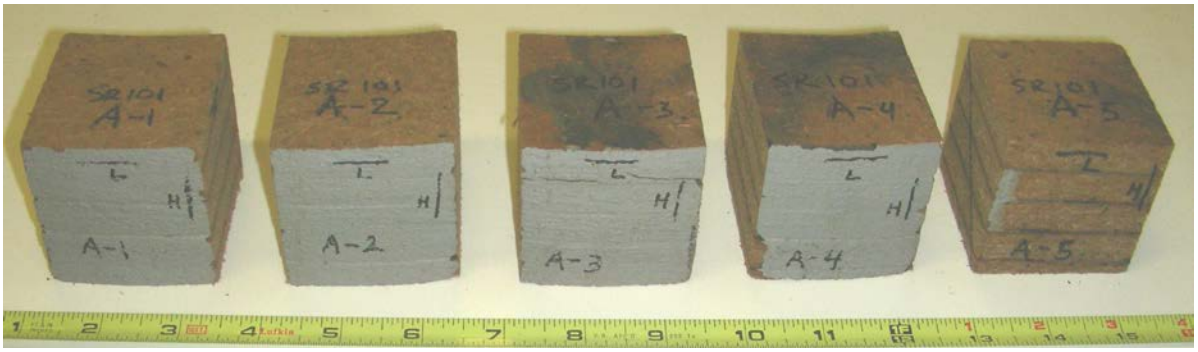
Figure 2. Separation of outer ring of upper assembly from packages 29 (left) and 39 (right)

Figure 3. Lower fiberboard assembly in drum for packages 29 (left) and 2 (right). The upper layer is detached in package 2.

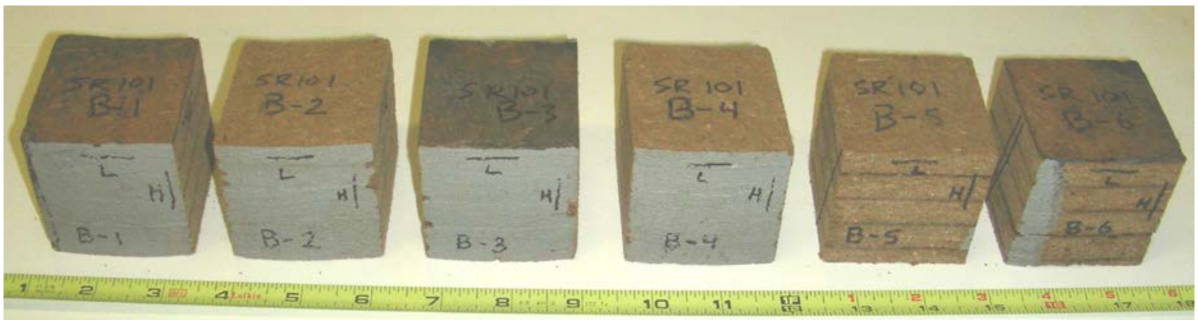
Figure 4. Method for removing lower assembly from drum, illustrated with package 2.

Figure 5. Lower assemblies removed from packages 39 (left) and 42 (right)

Figure 6. Detail of damaged surface from package 42 lower fiberboard assembly, with upper ring broken off.



(a)

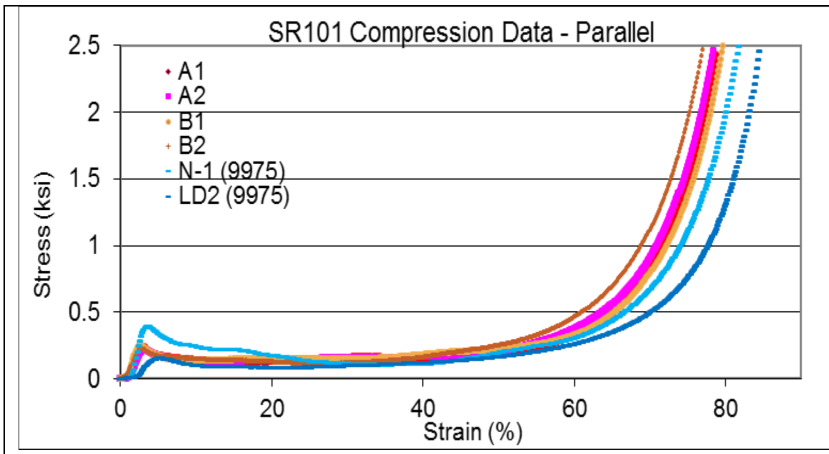


(b)

Figure 7. Compression samples from packages designated A and B. The coating has been removed from samples A5, B5 and B6.

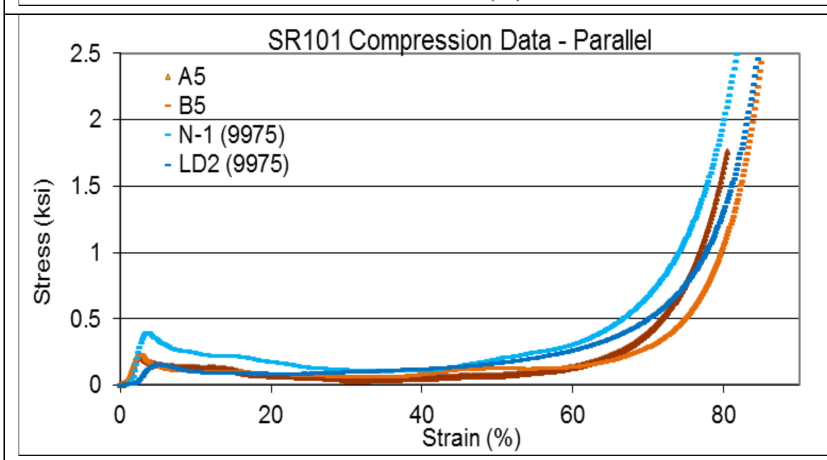
Figure 8. Detail of compression samples A1 and A5.

Figure 9. Detail of compression samples B3 and B6.



(a)

Sample	Absorbed Energy* (psi)	Buckling Strength (psi)
A1	57.0	240
A2	57.2	218
B1	58.6	251
B2	53.0	224
N-1 (9975)	69.8	393
LD2 (9975)	37.8	152

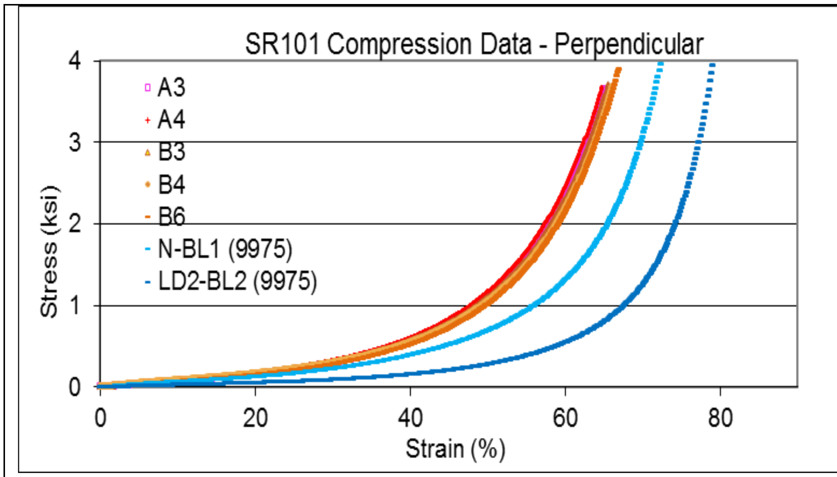


(b)

Sample	Absorbed Energy* (psi)	Buckling Strength (psi)
A5	32.0	210
B5	35.7	228
N-1 (9975)	69.8	393
LD2 (9975)	37.8	152

* Absorbed energy is represented by the area under the stress-strain curve up to 40% strain.

Figure 10. Stress-strain curves from compression tests in the parallel orientation. The blue curves show baseline data for 9975 fiberboard assemblies. The SR101 samples in (a) retained the coating on the front and back (OD and ID) surfaces. The samples in (b) had the coating removed.



Sample	Absorbed Energy* (psi)
A3	77.2
A4	83.6
B3	79.2
B4	78.7
B6	74.7
N-BL1 (9975)	60.9
LD2-BL2 (9975)	25.3
* Absorbed energy is represented by the area under the stress-strain curve up to 40% strain.	

Figure 11. Stress-strain curves from compression tests in the perpendicular orientation. The blue curves show baseline data for 9975 fiberboard assemblies. SR101 sample B6 had the coating removed, while the other samples retained the coating on the front and back (OD and ID) surfaces.

Figure 12. Sequence from compression tests of samples A2 and A5.

Figure 13. Sequence from compression tests of samples B1 and B5.

Figure 14. Thermal conductivity samples from packages designated A and B.

Figure 15. Thermal conductivity samples with sections separated for clarity. The registration lines ensure the sections remain in the correct position and orientation during testing.

Figure 16. Specific heat capacity samples from the package designated A.

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