Long-term Aging of Polyurethane Foam Used for Radioactive Materials Transportation Packages

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Abstract:

Transportation packages for radioactive material containers require durable materials to achieve the level of performance required by regulation to protect public health and safety during normal and accident conditions of transportation. General Plastics LAST-A-FOAM® FR-3700 series of rigid foam has been used to protect radioactive material containers for almost 50 years by mitigating the damage caused by impact energies and fire events.

General Plastics has conducted studies to advance the complete understanding of both the long-term durability of LAST-A-FOAM®, and the effects of knit lines created during our "pour in place" manufacturing process.

LONG-TERM AGING OF LAST-A-FOAM® FR-3700 SERIES

Introduction:

Both wood and polyurethane foams are used in the construction of radioactive material containers. As many of these radioactive material containers can be certified for decades of use, it is imperative that the construction material retains its physical properties over the normal life span of the application. This study reviews the material aging characteristics and its fitness for use in long-term use applications.

A long-term ongoing aging test started in 1997 at Portland General Electric's Trojan spent nuclear fuel dry storage facility, when the ISFSI impact limiter was first manufactured using LAST-A-FOAM® FR-3708. A second long-term and ongoing aging study of LAST-A-FOAM® and multiple wood species exposed to the elements, started in December of 1999 by General Plastics Manufacturing Company.

General Plastics summarizes the results of recent testing in these two long-term and on-going aging studies of LAST-A-FOAM® polyurethane foam over a 20-year period.

Experimental Conditions:

Enclosed Storage:

The enclosed storage samples are contained in a weather-tight, stainless steel enclosure stored at Portland General Electric's Trojan Spent Nuclear Fuel dry storage facility. In addition, each sample is wrapped with polyvinyl film. See Picture #1 for a view of the enclosed storage condition with the door open. The foam in the exposed storage condition did not show any biological contamination or water damage.

Picture #1- Enclosed Storage

Exposed Storage:

The unprotected storage conditions exposed the wood and foam materials year-round to the extreme environmental elements of the Pacific Northwest. The specimens were housed in a subterranean concrete vault with an open grate at the top. The foam and wood were equally exposed to dust, dirt, insects, seasonal Pacific Northwest weather and organic debris from surrounding plant life. See Pictures #2 and #3 below. The expanded metal boxes were removed from the vault and moved indoors to begin ambient conditioning for a period of one week prior to handling. The materials were lightly brushed clean of accumulated debris, but not re-surfaced. After cutting specimens to size, each were placed in a conditioning chamber for a minimum of 40 hours at 70 +/- 5° F, and 50 +/- 5% Relative Humidity prior to testing. The 1.0" thick dimension was tested as-is aside from the light cleaning.

Some of the wood material exhibited significant decay and damage due to the attack by fungus and insects. Specimens were cut from the best areas of the stock. The wood specimens received some light sanding to improve the surfaces contacting platens of the test machine. The only fresh-cut surfaces would be the test specimen perimeters, cut to achieve the final specimen size. Due to the overall higher compressive strength of the wood specimens, they were cut to 1" cubes to accommodate the capabilities of our universal test machine. The lower density foam specimens were also 1.0" thick, however the tested surface area was 2"x2".

Picture #2- Exposed Wood Samples

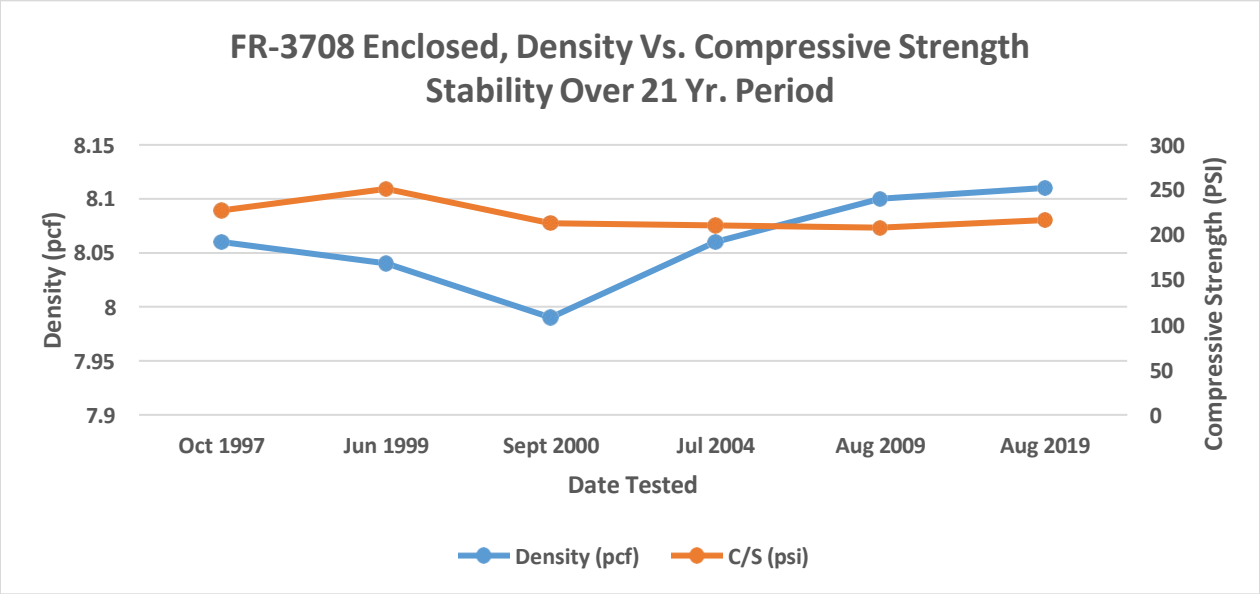
Picture #3- Exposed Foam Samples

Data:

Density tests were conducted in accordance with ASTM D-1622, with the use of a digital caliper and scale. ASTM D-1621 was used for compressive strength testing using a Shimadzu AG-X Plus 100 kN Universal Testing Machine. Five specimens were tested at each condition for each material.

Enclosed Storage:

FR-3708, Enclosed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Oct 1997	8.06	227.3
Jun 1999	8.04	251.0
Sept 2000	7.99	213.0
Jul 2004	8.06	210.4
Aug 2009	8.1	208.0
Aug 2019	8.11	216.4
Average	8.06	221.0
Std. Dev.	0.04	16.2



Exposed Storage (Foam and Wood):

All foam specimens were tested parallel to the rise of the foam when produced. All wood specimens were tested parallel to the vertical growth of the tree.

See Table #1 for LAST-A-FOAM® test results and Table #2 for wood test results.

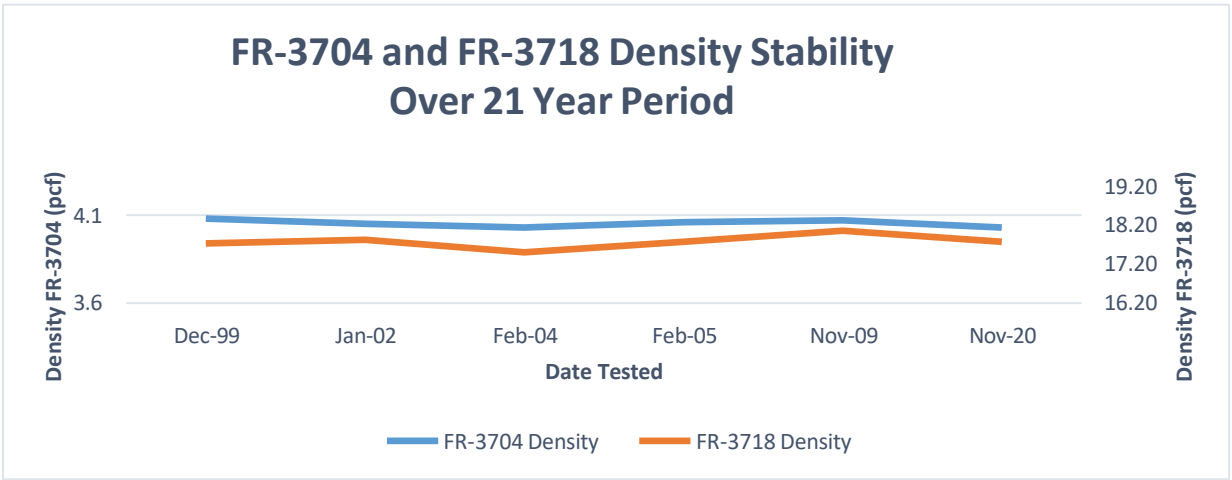
Table #1- LAST-A-FOAM® TEST SAMPLES AND TESTING RESULTS

FR-3704, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-99	4.08	46.9
Jan-02	4.05	56.6
Feb-04	4.03	52.9
Feb-05	4.06	68.0
Nov-09	4.07	78.3
Nov-20	4.03	74.9
Average	4.05	62.9
Std. Dev.	0.02	12.7

FR-3718, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-99	17.73	936.1
Jan-02	17.82	940.7
Feb-04	17.50	810.7
Feb-05	17.77	806.3
Nov-09	18.05	829.6
Nov-20	17.77	900.4
Average	17.77	870.6
Std. Dev.	0.18	62.4

The measured Density and Compressive Strength of the LAST-A-FOAM® specimens exhibited results consistent with normal product variation, with no apparent age or exposure-induced shifts in performance.

Comparative test data for the two densities of LAST-A-FOAM® is shown in the graphs below, representing tests conducted over the last 21 years.



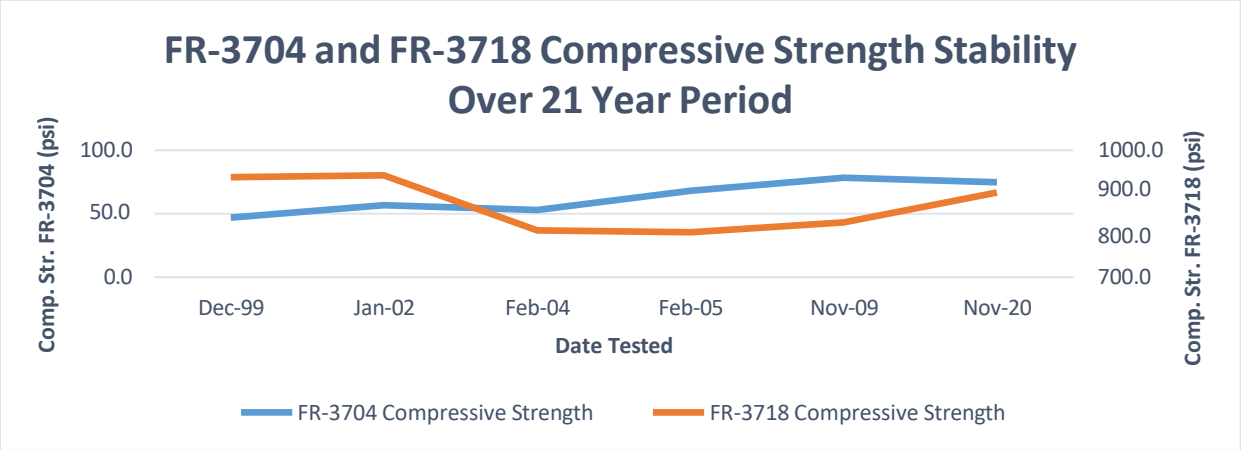
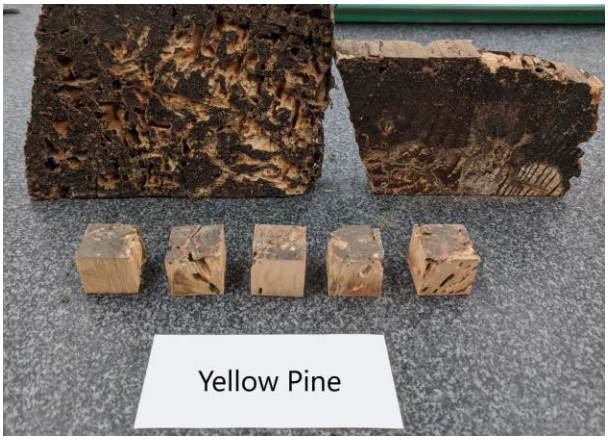


Table #2- WOOD SAMPLES AND TESTING RESULTS



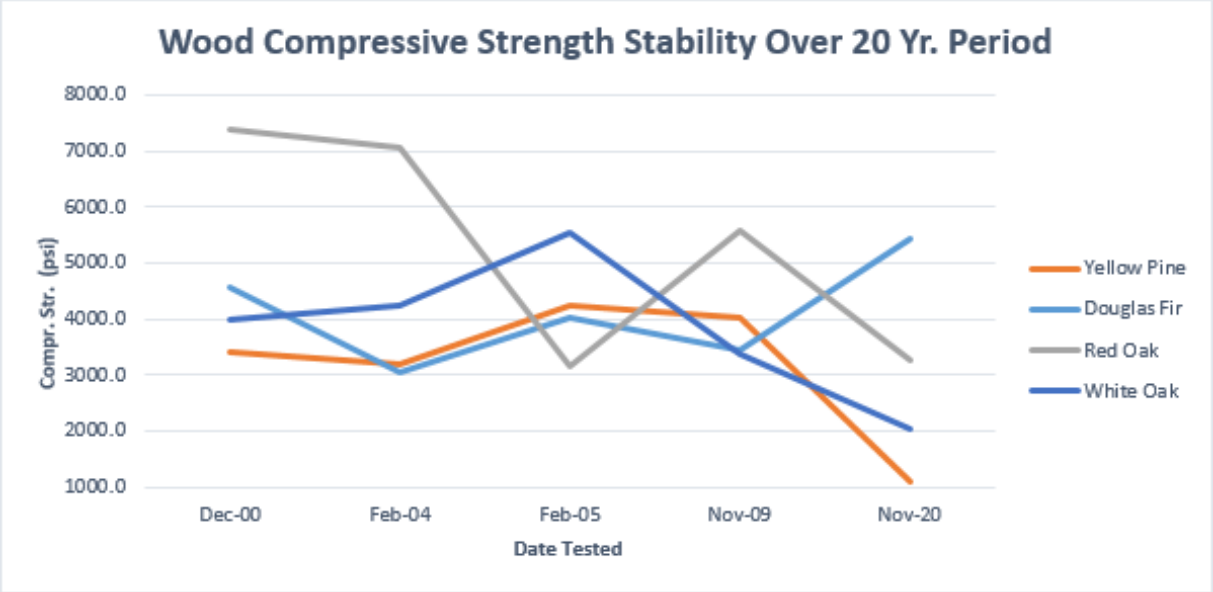
Yellow Pine, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-00	30.64	3411.6
Feb-04	27.33	3210.5
Feb-05	28.18	4242.0
Nov-09	25.78	4012.6
Nov-20	26.8	1081.6
Average	27.75	3191.66
Std. Dev.	1.84	1252.83

Douglas Fir, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-00	38.02	4583.5
Feb-04	54.22	3049.1
Feb-05	33.71	4020.1
Nov-09	36.30	3455.5
Nov-20	44.67	5429.3
Average	41.38	4107.50
Std. Dev.	8.24	938.98

Red Oak, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-00	46.17	7366.0
Feb-04	41.83	7062.4
Feb-05	46.90	3139.0
Nov-09	43.96	5575.3
Nov-20	37.75	3278.5
Average	43.32	5284.23
Std. Dev.	3.69	2012.80

White Oak, Exposed Storage		
Date	**Density (pcf)**	**C/S (psi)**
Dec-00	66.71	3989.0
Feb-04	44.82	4225.1
Feb-05	46.45	5528.2
Nov-09	46.54	3380.2
Nov-20	21.4	2048.0
Average	45.2	3834.1
Std. Dev.	16.1	1269.2

Comparative test data for the four species of wood is shown in the graphs below, representing tests conducted over the last 21 years.



Discussion:

Two storage conditions were employed for sample aging. One set of samples was aged in an enclosure to mimic the ISFSI impact limiter condition, and the other to mimic long-term aging when material is exposed to the elements. Only the FR-3708 foam samples were aged in the enclosed storage condition.

Neither the enclosed or exposed LAST-A-FOAM® material showed any significant decrease in density or compression strength after 20 years. The exposed LAST-A-FOAM® products showed the expected yellowing, typical of polyurethane products due to UV exposure. The condition was limited to the surface only. The 21-year-old cut specimens revealed virgin material as one would see with a newly produced material. Any moss growth found on the LAST-A-FOAM® material was supported by the underlying organic matter of leaves, dust and dirt, and not the foam material. The foam condition was consistent with independent fungal tests previously conducted that showed LAST-A-FOAM® products do not support fungal growth. (Ref. ASTM G21 and MIL-STD-810G1 Method 508.7)

In general, the wood samples showed various instability in both density and compression strengths after 20 years of exposure. Significant organic matter was observed on the wood material, including but not limited to mushrooms and moss. The wood samples, being susceptible to fungus and insects, exhibited significant decay. Of the four wood species included in this paper, the Douglas Fir performed better than other wood species over time. The Oak species, however, may not survive the next five years or yield specimens for continued testing planned for 2025.

As evident in the graphed performances, the foam exhibits exceptional resistance to harsh environmental and biological exposure and shows superior consistency in performance when compared to wood. While some darkening and soiling of the LAST-A-FOAM® exterior surfaces may occur, the closed-cell nature of the material ensures the environmental impacts do not encroach beyond the exposed surfaces. All foam samples exhibited virgin material when examined below the surface, and no negative effect on mechanical performance.

Conclusion:

In critical applications, where material stability over long durations in a variety of conditions is critical to ensure reliable performance, General Plastics' LAST-A-FOAM® products have shown to withstand the test of time. Whether within an enclosed steel casing, or exposed to the elements, LAST-A-FOAM® will not rot, decay or lose mechanical properties, ensuring the safe transport and storage requirements for the life of the nuclear packaging application.

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