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1009 DEVELOPING AN INSULATION MATERIAL FOR TYPE B SHIPPING CONTAINERS

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Abstract

The Y-12 National Security Complex develops Type B shipping containers for various U.S. Department of Energy (DOE) missions. For the past 10 years, new shipping container designs used a cast ceramic material as the insulation in the outer drum for the purpose of impact limiting and thermal resistance. The material used in these containers has been a commercial product known as Kaolite 1600™, which is a pre-mix concrete product. During current fabrication of the Y-12 container known as the MD-2, the Kaolite 1600™ "after-casting" density was slightly above the required density in the container design specifications. After repeated sample castings of Kaolite 1600™, an acceptable density could not be achieved. Over a subsequent 6-month period, Y-12 worked with the supplier to understand the discrepancies and several attempts were made to re-create the original product. The end result was that changes in the batch mixing process and origin of raw materials produced a slightly different final product, and the original product could not be re-created by this manufacturer. Kaolite 1600™ still meets the needs of industrial users, but no longer meets the precise property requirements needed for Y-12 containers. It became apparent that Y-12 would have to substitute this material in the MD-2 and all future container fabrications.

To replace Kaolite 1600™, Y-12 initiated a program to develop a new, but similar material. A mixture was made with essentially the same ingredients as Kaolite 1600™, but mixed to more exacting proportions. The new mixture, termed Packcrete, has comparable material properties to Kaolite 1600™, as seen in laboratory testing. Specific mechanical and thermal tests were designed to show equivalent properties to Kaolite 1600™, as analyzed in the MD-2 Safety Analysis. Moving forward, Y-12 plans to fabricate MD-2 prototypes with Packcrete and subject them to full-scale regulatory drop and burn testing in accordance with US Code of Federal Regulations (10 CFR 71.71 and 71.73).

Introduction

The insulating material in a typical Type B shipping container, has two functions: energy absorption and thermal insulation. These functions are extremely important to the safe performance of the container during accident (drop, crush and puncture) conditions as required by the Nuclear Regulatory Commission (NRC). To perform these functions, the insulation must completely surround the inner core of the container which holds the radioactive material contents. A cross-sectional view of the MD-2 container, as seen on Figure 1, shows the insulation component of this assembly. The use of an inner liner attached to the drum body near the lid creates an annular space in which the insulation is cast in place. The type of material used for insulation and the thickness will dictate how well the package performs during normal and accident conditions, as defined in the US NRC Code of Federal Regulations 10 CFR 71.71 and 10 CFR 71.73 [Ref 1]. Early versions of the MD-2 container successfully performed during normal and accident conditions using Kaolite 1600™ as the insulating material. Encapsulated insulation has been shown on other containers to reduce life-cycle costs by reducing package refurbishment and maintenance efforts.

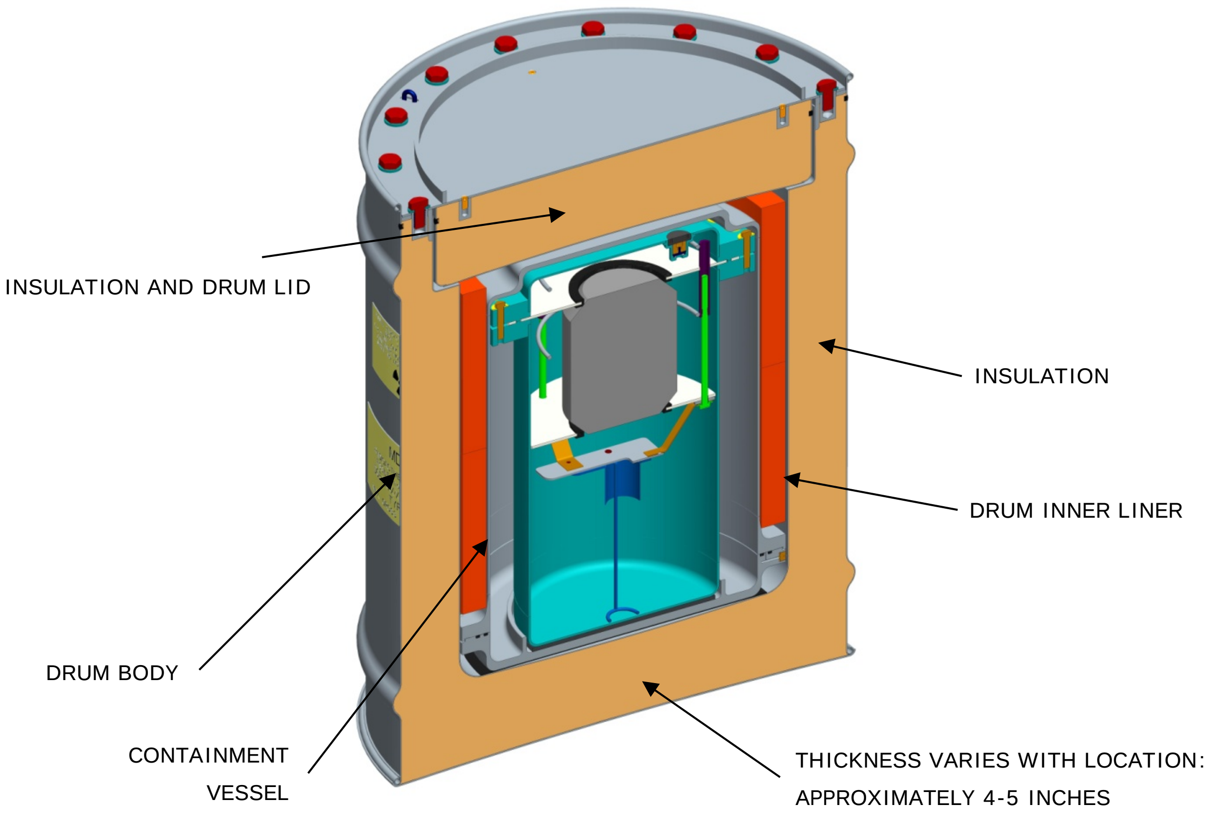

Figure 1. Section view of the MD-2 container.

Packcrete Formula Development

When Kaolite 1600™ was no longer commercially available to fabricate new MD-2s, another commercial material had to be identified or a new material had to be invented that gave similar characteristics and properties as Kaolite 1600™. Extensive search could identify another commercial product with similar and consistent characteristics and properties.

The two primary components of Kaolite 1600™ were known, so Packcrete development started with these same two ingredients. The first ingredient is Type III Portland cement (very common) complying with American Society of Testing and Materials (ASTM) requirement ASTM C150-12. The second ingredient is vermiculite, which is fairly common and readily available from several sources. The vermiculite needed here is Type I (exfoliated), Grade 3 that meets ASTM C516-08. Exfoliation is a high temperature process that essentially “fluffs” the vermiculite particles and effectively lowers the bulk density of the material. The final ingredient is known as an additive and is only present to aid in the mixing process. The additive used in Packcrete was Airalon® 3000. This material meets ASTM C260-10a.

Packcrete is a custom material made by mixing precise proportions of water, Portland cement, vermiculite, and additive for a predetermined amount of time. The mixture is then cast in place, allowed to cure at ambient temperature, and then baked for final curing. When these ingredients are mixed, cured, and baked, the result is a material very similar to Kaolite 1600™ in both appearance and density. Figure 2 shows both materials after mixing, curing and baking. The consistency of the material shown here (rigid foam) is most beneficial for energy absorption and thermal insulation in a Type B shipping container.

Figure 2. Discs of Kaolite (on left) and Packcrete after baking.

Sample Casting of Packcrete

To fully understand the formula for Packcrete and to insure repeatability, samples were cast with several different formulas, each time varying the ratio of Portland cement to vermiculite. The final baked density range of interest during development of Packcrete was the same as Kaolite, specifically 19.4 to 25.4 lb./ft^3 (nominal 22.4 lb./ft^3). One of the principle parameters of this material is the final density. As in the case of the previous material, Kaolite 1600™, a density in the specified range gave the properties needed for package performance per the NRC regulations. Final density is often referred to as final baked density, because the final step in producing this material is to bake at steadily increasing temperatures up to a final temperature of 500° F. Baking drives off water to not only reach the desired density, but to control the amount of latent water in the material to support criticality calculations in the Safety Analysis Report.

The weight ratios of Portland cement and vermiculite were varied to achieve final baked density throughout this range. It was not necessary to vary the amount of additive in each batch, as that component is only used in small quantities and does not affect the final properties of Packcrete. As part of the development process, sample batches were created to achieve the extra low end of the density range of ~20-21 lb./ft^3, the low end of the density range of ~21-22 lb./ft^3, the nominal density range of ~22-23 lb./ft^3, and the upper end of the density range of ~23-24 lb./ft^3. The various sizes and shapes used for these samples are shown in Figure 3.

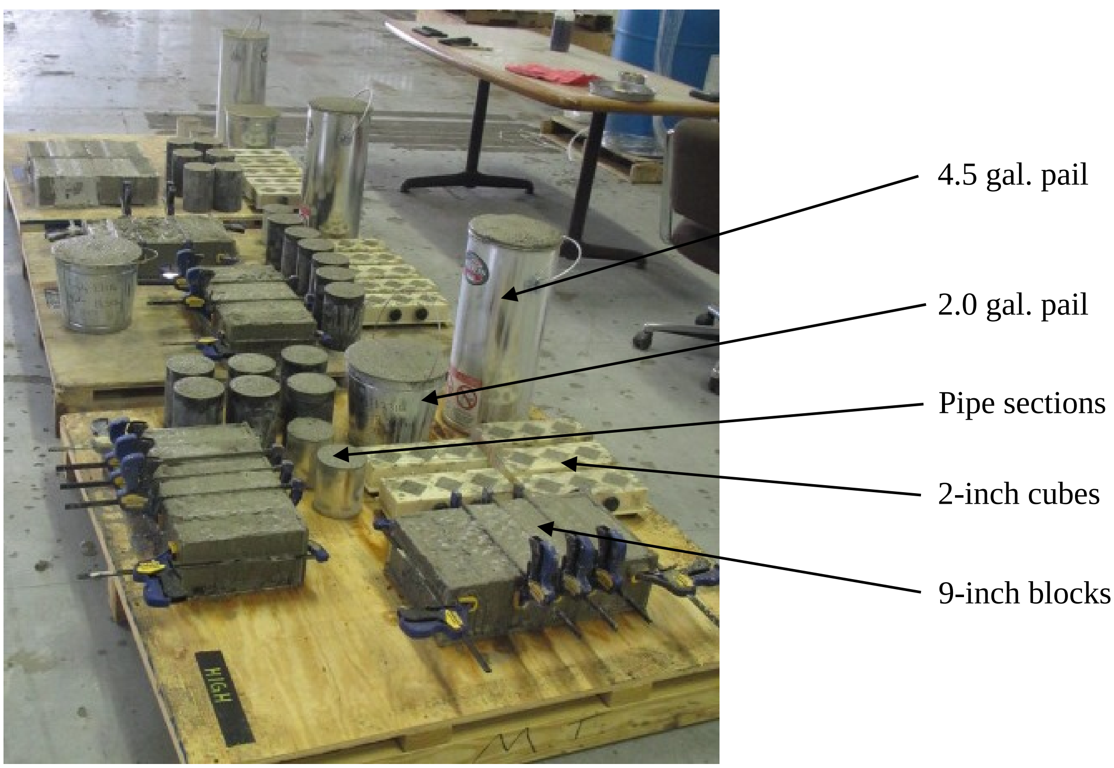

Figure 3. Packcrete development sample sizes and shapes.

Table 1 shows the casting results for the sample shapes shown on Figure 3 for the nominal density range trials. Using varies shapes and sizes assures repeatability of the process and gives data on consistency of the process. From the results in Table 1, it is seen that casting into a more confined configuration, such as the pails and pipes, gave the most satisfactory final densities (e.g. in the desired range of 19.4 to 25.4 lb./ft^3). You can conclude from this that the material will behave as required in the configuration of the MD-2 shipping container.

Table 1. Samples created representing the nominal density range (22-23 lb./ft^3).

		R108														
2 Gallon Pail	**Marking**	**R108-2G1**														
	Volume (ft3)	0.27														
	wet cast (lb)	16.00														
	wet density (lb/ft3)	54.23														
	after bake	7.17														
	baked density (lb/ft3)	21.85														
4.5 Gallon Pail	**Marking**	**R108-4.5G**														
	Volume (ft3)	0.63														
	wet cast (lb)	37.12														
	wet density (lb/ft3)	53.95														
	after bake	16.77														
	baked density (lb/ft3)	21.81														
9" Bricks	**Marking**	R108-B1	R108-B2	R108-B3	R108-B4	R108-B5	R108-B6	R108-B7	R108-B8	R108-B9	R108-B10	R108-B11	R108-B12	--		
	Height	8.94	8.97	8.95	8.99	8.97	8.99	8.97	8.98	8.97	8.98	8.94	8.97	--		
	Width	2.50	2.51	2.52	2.50	2.50	2.50	2.52	2.51	2.51	2.50	2.52	2.50	--		
	Depth	4.49	4.52	4.51	4.53	4.56	4.59	4.52	4.54	4.52	4.52	4.54	4.57	--		
	Volume	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	--		
	after bake	1.42	1.53	1.48	1.66	1.59	1.62	1.51	1.49	1.61	1.51	1.43	1.54	--		
	baked density (lb/ft3)	24.45	25.98	25.14	28.17	26.87	27.14	25.54	25.16	27.34	25.71	24.16	25.97	--		
2" Cubes	**Marking**	R108-C1	R108-C2	R108-C3	R108-C4	R108-C5	R108-C6	R108-C7	R108-C8	R108-C9	R108-C10	R108-C11	R108-C12	R108-C13	R108-C14	R108-C15
	Height	1.99	2.00	2.01	1.99	1.99	1.99	2.00	2.00	2.00	2.00	1.99	2.00	2.00	1.99	2.01
	Width	1.99	2.01	1.99	2.00	1.99	1.99	1.99	1.99	1.98	1.99	1.99	1.99	1.99	1.99	2.01
	Depth	2.00	1.99	2.01	1.99	1.99	1.99	2.00	1.99	1.98	1.98	1.98	1.98	1.98	1.98	1.98
	Volume	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	after bake	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	baked density (lb/ft3)	26.18	25.92	25.79	26.18	26.31	26.31	26.05	26.18	26.45	26.31	26.45	26.31	26.31	26.45	25.92
Pipes	**Marking**	**R108-P1**		**R108-P2**		**R108-P3**		**R108-P4**		**R108-P5**		**R108-P6**		--		
	Pipe ID	4.06		4.06		4.07		4.05		4.06		4.06		--		
	clean empty	5.44		5.45		5.41		5.45		5.43		5.41		--		
	after bake	6.16		6.15		6.14		6.16		6.16		6.13		--		
	BIH (in)	4.06		4.06		4.06		4.02		4.02		4.06		--		
	Volume	0.03		0.03		0.03		0.03		0.03		0.03		--		
	baked density (lb/ft3)	23.67		23.01		23.88		23.69		24.24		23.67		--		

To further test the theory about repeatability and property consistency, casting into larger specimens was conducted. Two following two larger specimens were selected: a larger 30 gallon drum and a simulated MD-2 drum. The simulated MD-2 drum was an 85 gallon drum with a 30-gallon drum inside to create the annular space, thus simulating an actual MD-2 (Figure 4).

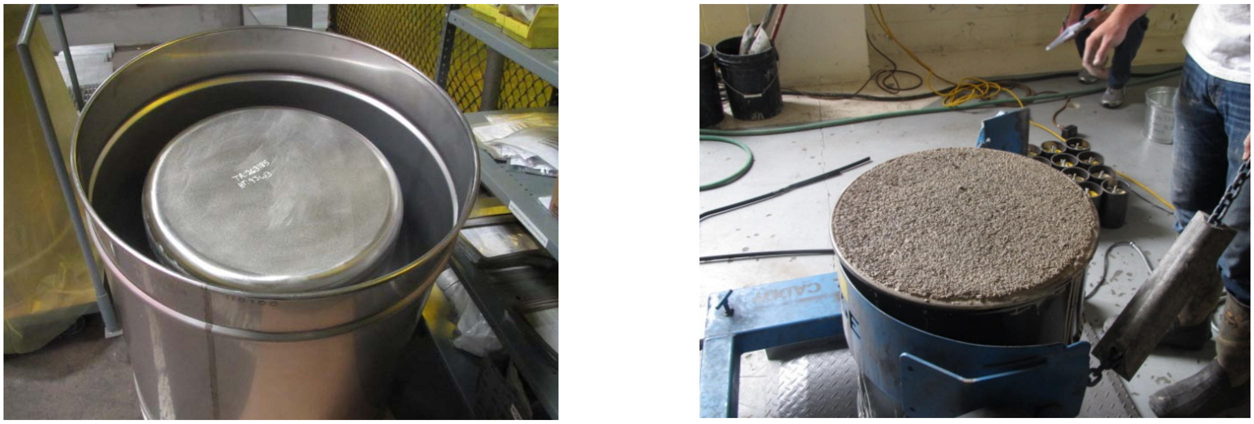

Figure 4. Simulated MD-2 drum casting sample (before and after casting).

The results for the 30-gallon test samples are given in Table 2. Densities were slightly high for the nominal case, but still well within the acceptable range. This final 85-gallon casting test used formulas in the entire range of acceptable baked densities. Simulated MD-2s were cast with Packcrete using the formulas to achieve the extra low end of the density range of ~19-20 lb./ft^3, the low end of the density range of ~20-21 lb./ft^3, the nominal density range of ~22-23 lb./ft^3, and the upper end of the density range of ~23-24 lb./ft^3. Results of this test are given in Table 3. As shown, the densities desired for each test were achieved indicating repeatability of Packcrete mixing by adhering to the formula and by weighing ingredients on a container by container basis.

Table 2. Cast results for a 30-gallon drum sample representing the nominal density value (22.4 lb./ft^3).

Sample	RM-30G1	RM-30G2	RM-30G3	RM-30G4	RM-30G5	RM-30G6
clean & empty (lb)	27.5	28.5	27.5	26.5	27.5	27.5
water weight (lb)	289.5	290	289	287.5	289	290
Volume (ft3)	4.21	4.20	4.20	4.19	4.20	4.21
wet cast (lb)	256.50	259.00	254.50	243.00	250.00	255.00
wet density (lb/ft3)	54.45	54.91	54.08	51.68	53.01	53.99
after bake 1 (lb)	137.00	142.00	135.00	135.00	134.00	134.00
baked density 1 (lb/ft3)	26.04	27.04	25.61	25.90	25.37	25.28
after bake 2 (lb)	129.00	132.00	129.00	127.00	127.00	129.00
baked density 2 (lb/ft3)	24.14	24.66	24.18	23.99	23.70	24.09

Table 3. Casting and baked density for simulated MD-2 Packcrete tests.

Casting Parameter/Test Unit	SMD2[1] Nominal[2]	SMD2 High[3]	SMD2 Low[4]	SMD2 Ex-low[5]
Vermiculite dry weight (%)	37.5	35.5	39.5	41.5
Empty (lb)	89.5	87.5	88.0	87.0
With Water (lb)	547.5	548.0	548.5	547.5
Volume (ft^3)	7.4	7.4	7.4	7.4
Wet Cast Weight (lb)	485.0	493.5	481.0	468.0
Wet Denstiy (lb/ft^3)	53.8	54.9	53.2	51.5
Weight after scrape 3/12/2014 (lb)	476.0	483.5	470.5	457.5
Wet Density after scrape (lb/ft^3)	52.6	53.6	51.8	50.1
Baked Weight (lb)	254.5	262.5	247.5	239.5
Baked Density (lb/ft^3)	22.4	23.7	21.6	20.6

1. SMD2 – Simulated MD-2 Drum
2. Nominal – density range of 22-23 $lb./ft^3$
3. High – density range of 23-24 $lb./ft^3$
4. Low- density range of 21-22 $lb./ft^3$
5. Extra low – density range of 20-21 $lb./ft^3$

Qualification and Regulatory Approval

Replacement of a material of construction in a Type B, certified shipping container requires compliance with 10 CFR 71.19 (d) [Ref 1]. Compliance with this regulation and qualification of the material is a two-fold process. It first requires demonstration that the physical properties of the replacement material (Packcrete) are equivalent to the licensed material (Kaolite 1600™). The property measurements will show that Packcrete has physical properties and critical characteristics that are sufficiently similar to Kaolite 1600™ such that the performance response during normal conditions of transport and hypothetical accident conditions would be equivalent. Then, the second part of the process will demonstrate the actual performance response of an MD-2 with Packcrete under regulatory test conditions specified in 10 CFR 71.71 and 71.73 [Ref 2].

For the first part of the process, properties of Packcrete are being measured by certified testing laboratories using the various samples that were shown in Figures 3 and 4. The properties being measured are the following:

- Density
- Chemical Composition
- Thermal Conductivity
- Specific Heat
- Linear Thermal Expansion

- Cold Crush Strength
- Dynamic Impact Strength
- Modulus of Rupture
- Poisson's Ration

The MD-2 carries an Offsite Transportation Certificate (OTC) issued by the NNSA regulatory organization, specifically NA-00-40 [OTC: DOE/NNSA/20097/B(U)F]. For the regulator to see compliance of the MD-2 insulation replacement with 10 CFR 71.19(d), the MD-2 design agency will present the results of the Hypothetical Accident Conditions tests as described in 10 CFR 71.73. These tests are planned for early calendar year 2017. These test results will be compared to prior regulatory testing of MD-2s with Kaolite insulation [Ref 3].

Conclusions

Replacement of a safety significant component of a Type B shipping container requires extensive redesign, unless the replacement material and configuration are as close to the original material and configuration as possible. In the case of the MD-2, replacing Kaolite 1600™ with the similar material Packcrete will minimize these impacts. Equivalency will be demonstrated by showing 1) both materials use the same raw ingredients mixed to the same ratios, 2) mechanical and chemical properties of both materials are the sufficiently equivalent, and 3) the performance of both containers under regulatory normal and accident test conditions are the same. At this time, the MD-2 design agency has successfully completed the first part and is in the process of completing the second part. Preliminary results of property testing show both materials have the same mechanical and thermal properties. For the third part, plans are underway to conduct full-scale regulatory testing. The design agency is confident that the MD-2 will show the same performance with Packcrete as it did with Kaolite 1600™ during the original regulatory tests that supported licensing of the MD-2 in 2008.

Acknowledgements

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or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

References

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2. U. S. Nuclear Regulatory Commission, 10 CFR 71, Section 71, Normal Conditions of Transport, and Section 73, *Hypothetical Accident Conditions*.

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