HIGH-IMPACT CONCRETE FOR FILL IN U.S. DEPARTMENT OF TRANSPORTATION TYPE SHIPPING CONTAINERS

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ABSTRACT

This report describes the use of light-weight, high-impact concrete in U.S. Department of Transportation-type shipments. The formulations described are substantially lighter in weight (20 to 50 percent) than construction concrete, but product test specimens generally yield superior impact characteristics. The use of this specialty concrete for container fill, encapsulations, or liquid-waste solidification can be advantageous. Use of the material for container or cask construction has the advantage of lighter weight for easier handling, and the container consistently exhibits better performance on drop tests. High-impact concrete does have the disadvantage of less gamma radiation shielding per volume, but some formulation changes discussed in this report can be used to prepare better shielding concrete. Test characteristics of high-impact concrete are included.

INTRODUCTION

Cement and concrete formulations are routinely used in U.S. Department of Transportation type containers in the nuclear industry. Concrete is used for fabricating casks, shipping containers, and waste burial packages. It is also used for fill in waste containers or vessels designated for disposal. Cement mixes are often used to solidify radioactive liquid wastes or encapsulate radioactive sources. Light-weight, high-impact concrete formulations can probably be used in all of the typical cement and concrete applications and provide superior performance characteristics except where maximum gamma radiation shielding is required.

CONTAINER DROP TESTS

The Title 10, Code of Federal Regulations, Part-71 (1) lists container tests, including a 9-m (30-ft) drop test that is required for Type B and fissile shipping containers. Container damage and loss of contents during transport accidents are an important safety concern during movement of radioactive materials. The use of high-impact concrete described in this report is designed to meet drop-test-type impacts. Most of the typical cement and concrete-type products used in industry are brittle and tend to break up under strong impacts. High-impact concrete, however, absorbs the impact energy (often by shape deformation) and resists breakup. Test blocks without containment were dropped 9 m and impacted a hard surface with little or no material dispersal.

WEIGHT LIMITATIONS ON SHIPMENTS

Transport of radioactive materials, particularly waste materials, is faced with an increasing number of regulations and limitations. One important limitation is weight restriction. At the Westinghouse Hanford Company, the contents of 208-liter steel drums routinely used for class A or fissile shipment of radioactive materials are limited to 380 kg (U.S. Department of Transportation 17-H and 17-C drums), including the weight of the drum, which is about 23 kg. General U.S. Department of Energy restrictions allow 408 to 454 kg depending on the contents of the drum.(2) The 380-kg limit restricts the density of the contents to about 1.70 kg/L, or the drum can be only partially filled. This compares with a minimum density of 2.3 kg/L for ordinary construction concrete.

The remote-handled, transuranic (TRU) waste scheduled for shipment to the Waste Isolation Pilot Plant (WIPP) is limited to 3,628 kg for a 3.04-m-long package with a 66-cm diameter.(3) This amounts to a product density of about 0.90 kg/L. Similarly, the Transuranic Package Transporter (TRUPACT) overpack container used for contact-handled TRU waste is limited to an average of 227 kg per drum, or about 1.06 kg/L. The use of ordinary concrete or even similar portland cement mixes without aggregate for fill, encapsulation, or immobilization purposes could exceed weight limitations for full containers and therefore require either partial filling or use of a different material. This report shows how to substitute low-weight, high-impact concrete formulations for ordinary concrete or portland cement mixes and still achieve a product that can withstand transport-type accident impacts as good or better than the heavier weight concrete or cement.

USE OF LIGHT-WEIGHT CONCRETE

Light-weight concrete was recently used as fill material in Hanford Site containers. Large containers destined for burial are required to be filled with concrete or other solid filler material to accomplish the following: (a) prevent burial-trench subsidence as containers corrode away, (b) fix or immobilize inner-radioactive-contamination sources, and (c) provide gamma and neutron radiation shielding. Concrete was chosen as a fill material, in part, to fix contamination to prevent any possible accidental release. The light-weight concrete was used for the fill of two uranium-contaminated gloveboxes with an approximate size of 2.8 m x 2.3 m x 0.9 m, shown in Fig. 1.

The light-weight concrete was also used to fill a uranium contaminated 11,355-liter stainless-steel storage tank shown in Fig. 2.

Fig. 1. Burial Glove-Box Requiring Fill Material.

Fig. 2. Burial Tank (11,355 L) Requiring Fill Material.

Fig. 3. Concrete Pump Used for Filling Burial Containers.

Vermiculite concrete (4 volumes of vermiculite to 1 volume of portland cement) was chosen as the fill material. The estimated wet density of the concrete was expected to be about 1 kg/L (roughly equivalent to water). Alternatively, a perlite concrete could have been used. The perlite-concrete wet density for the same 4 to 1 mix would have been expected to be about 0.8 kg/L. The vermiculite concrete was chosen because of previous positive experiences with this material.

The container fill operation was attempted using a cylinder displacement concrete pump shown in Fig. 3.

Unfortunately, the pump would not work (prime) with the vermiculite-concrete mix selected. Testing showed that 274 kg of sand per yard of concrete had to be added to the mix to make it pumpable. The composition was adjusted, and the fill proceeded. The use of a different style pump, tested for vermiculite-concrete, would have been an acceptable alternative. The fill was accomplished with the heavier mix, but the product was still much lighter than ordinary concrete. The characteristics of the vermiculite-concrete,

and the vermiculite-concrete with sand, showed higher than expected densities. Product characteristics are given in Table I along with other common fill materials for comparison.

IMPACT STRENGTH OF LIGHT-WEIGHT CONCRETE

The relative impact strength[*] of light-weight vermiculite concrete was determined *as a function of the* vermiculite content. The impact strength was measured using an appa-

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[*] Strength typically is defined as "power to resist force." Impacts deal with force applied over a distance. Impact strength for this report is defined as "power to resist energy" and measurements are listed in joules per area impacted (J/cm^2).

TABLE I
Fill Materials

Material	Solid form	Density (kg/L)	Compression strength (kg/cm^2)
Vermiculite	particulate	0.8 to 0.11	
Perlite	particulate	0.11	
Clay granules	particulate	0.5 to 0.9	
Sand	particulate	1.5 to 1.8	
Vermiculite-concrete	monolith	1.0 expected	35
		1.30 actual	37
Vermiculite-concrete with sand		1.31 expected	--
	monolith	1.46 actual	37
Construction concrete	monolith	~2.30	141 to 176
Solidified cement (no aggregate)	monolith	~1.97	105 to 141

TABLE II
Impact Strength of Light-Weight Vermiculite Concrete.

Sample No.	Vermiculite content (%)	Density (kg/L)	Compression strength (kg/cm^2)	Impact strength (J/cm^2)
1	0	2.18	388	0.30
2	2.3	1.75	244	0.30
3	4.4	1.56	380	0.60
4	6.0	1.43	75	0.45
5	7.3	1.31	35	0.45

ratus that dropped various stainless steel weights were of the same surface area from a height of 76 cm onto a 2.5-cm-thick concrete target with a diameter of 18 cm. Sequentially increasing mass weights dropped until the target broke completely through. Compression strength measurements (7-day) were also taken for comparison purposes, although there were usually no correlations between impact strength and compression strength. The measurements are listed in Table II.

The results indicated that the addition of fine-particulate-size vermiculite material did at least maintain the impact strength of the product and perhaps improved it. Therefore, a lighter-weight concrete might be expected to have as good or better impact strength than a heavier one. This conclusion was confirmed by additional tests using coarser particulate vermiculite material.

REINFORCING LIGHT-WEIGHT CONCRETE

Impact tests on the light-weight concrete indicated that the addition of light-weight absorbing material such as vermiculite or perlite to cement mixes decreases the brittle character of the concrete product. However, application of impact forces to light-weight concrete broke up targets and scattered target material. It became obvious that a reinforcing material was needed in the test concrete to minimize dispersion of material and to minimize cleanup for any potential accident condition. A series of tests was conducted to further substantiate this conclusion and to take a quick look at the effects that different materials have on impact strength. The materials and the results are given in Table III.

Based on the results given in Table III, a commercially available synthetic-fiber reinforcing material called Fibermesh* was chosen as the most likely material to use for the light-weight, high-impact-strength concrete preferred for fill. Some of the advantages of Fibermesh material and equivalent synthetic fibers are their light weight, their low cost, and the ease with which they can be added to cement mixes. A heavier alternate that might perform well

TABLE III
Comparative 7-day Impact and Compression Strength Tests.

Concrete description (aggregate used)	Density (kg/L)	Compression strength (kg/cm^2)	Impact strength (J/cm^2)
Ground limestone	2.24	338	>0.75
Copper turnings	2.02	338	>0.75
Sectioned wire	1.92	189	>0.75
Glass wool	1.85	89	>0.75
Steel wool	1.81	70	>0.75
Fine vermiculite	1.50	50	>0.75
Coarse sand	2.24	278	0.39 to 0.75
Medium gravel	2.37	159	0.39 to 0.75
Fine gravel	2.32	120	0.39 to 0.75
Hazorb[a] absorbent	1.48	89	0.39 to 0.75
Powdered clay	2.03	70	0.39 to 0.75
Cement only (no aggregate)	1.95	278	<0.39
Medium sand	2.21	179	<0.39
Pumice rock	1.81	159	<0.39
Corn cob absorbent	1.49	10	<0.39

[a] Hazorb is manufactured by Occidental Electrochemical Corporation, Dallas, Texas.

TABLE IV
The Effects of Fibermesh Content On Concrete Strength

Sample No.	Fibermesh content (%)	Compression strength (kg/cm^2)	Impact strength (J/cm^2)
1	0	129	0.30
2	0.04	179	0.45
3	0.08	134	0.74
4	0.19	164	0.90
5	0.31	139	0.90
6	0.46	164	1.05
7	0.57	139	1.22

for gamma-shielding concrete is Fibercon* steel fiber or equivalent metal-fiberous materials.

THE EFFECT OF FIBERMESH ADDITION ON CONCRETE STRENGTH

Sample mixes of light-weight concrete containing fine-particulate vermiculite adjusted to 4.3 wt% were made from type II portland cement. Varied amounts of Fibermesh

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* Fibermesh is manufactured by Fibermesh Incorporated, Chattanooga, Tennessee.

TABLE V
Performance of Concrete Drop Test Specimens.

	Composition					
Sample No.	Cement %	Sand %	Gravel %	Verm. %	Fiber %	Water %
1	14	20	58	0	0	8
2	20	15	43	5	0	17
3	19	14	40	5	0	22
4	19	14	39	6	.08	22
5	14	21	57	0	0	7
6	36	0	0	14	0	7
7	34	0	0	15	.15	51

Sample No.	Density (kg/L)	7-Day compression strength (kg/cm^2)	Impact strength (J/cm^2)	Product dispersal %
1	2.47	75	0.30	10.0
2	1.86	25	0.30	6.3
3	1.71	150	0.45	2.3
4	1.83	150	0.60	0.1
5	2.50	115	0.45	0.9
6	0.96	5	0.30	0.2
7	0.95	7	0.60	0

* Fibercon steel fiber is manufactured by USX Steel Corporation, Pittsburgh, Pennsylvania

Fig. 4. Reinforced Vermiculite Concrete Specimen

material were added to the cement compound and mixed at least 5 min before taking test samples. Next the concrete samples were tested for compression and impact strength. The measurements are given in Table IV.

The results showed that increasing the Fibermesh content increased the impact strength of the concrete product. The Fibermesh became increasingly difficult to mix in as the content increased above 0.5 percent; therefore higher additions were not tested.

THE EFFECT OF IMPACTS ON CONCRETE TEST SPECIMENS

The general results included in this report are confirmed by testing the effect of the 9-m drop impact on various concrete test specimens. The percent of dispersal (particulate below 1 mesh) is listed in Table V along with the general compositions of the concrete test specimens. A mixture of fine, medium, and coarse gravel (usually in equal parts) was used to make the concrete. Densities range from a high of 2.5 kg/L for construction-type concrete to a low of 0.95 kg/L for vermiculite concrete.

Fig. 5. A Concrete Speciment Exhibiting Lower Impact Resistance.

The results showed that the reinforced vermiculite-concrete exhibited the best drop-test characteristics. The reinforced vermiculite-concrete or an equivalent type (reinforced perlite concrete) appear to offer the most impact-resistant concrete for many of the common uses in the nuclear industry. Fig. 4 shows an example of reinforced vermiculite concrete that exhibited neither loss nor dispersal of material from the drop-test impact. Fig. 5 shows a concrete specimen that exhibited a 10 percent loss of material upon impact but contained neither vermiculite nor reinforcing material. All the test specimens were essentially the same size (3.8-L volume).

SOLIDIFICATION OF LOW-LEVEL LIQUID WASTES

Compositions of light-weight vermiculite and one perlite mix were reinforced with Fibermesh materials and tested for use in solidifying simulated sodium sulfate and sodium nitrate-type liquid wastes. Sodium sulfate solutions and mixtures are typical radioactive (reactor) waste liquids, and sodium nitrate solutions are typical fuel-processing waste liquids. These two liquids were solidified (using a salt concentration at or near 20 wt%) with low-weight, high-impact concrete formulations. The 7-day product characteristics were compared with cement-solidified products. The laboratory test results are given in Tables VI and VII.

The measurements given in Tables VI and VII show that a light-weight, high-impact-strength concrete formulation can be used for liquid-waste solidification to fix almost as much liquid waste with only about 60 percent the weight of cemented products. The products also exhibited higher impact strengths than cemented-liquid-waste products.

Representative blocks of the same composition were dropped in the form of cylindrical-shaped solids from a height of over 9 m to a steel pan target resting on a hard asphalt surface. Fig. 6, 7, and 8 show examples of impact strength and drop-tested blocks. These tests show that the light-weight reinforced concrete specimens with simulated liquid-waste exhibit as much or more impact strength than the heavier cemented solids.

Fig. 6. Impact-Strength Test Speciments--Cement (left) versus Light-Weight, Reinforced Vermiculite-Concrete (right) Used for Solidifying Sodium Sulfate Liquid.

CONCLUSIONS

1. Light-weight concrete can be used as good fill material for waste burial containers, particularly if an accident-resistant material is required or desired.
2. The addition of light-weight absorbing materials to cement as an aggregate generally will maintain or increase the impact strength of the resulting concrete product.
3. Use of a light-weight, high-impact strength concrete formulation, such as reinforced vermiculite-concrete, appears to be an excellent candidate for liquid-waste solidification, particularly when lighter weight products have economic advantages.
4. Use of reinforced, vermiculite-concrete would allow DOE generators of TRU contaminated liquid waste to solidify their material and still meet WIPP and and WIPP Transport limitations, with little or no reduction of their waste packaging efficiency (no appreciable

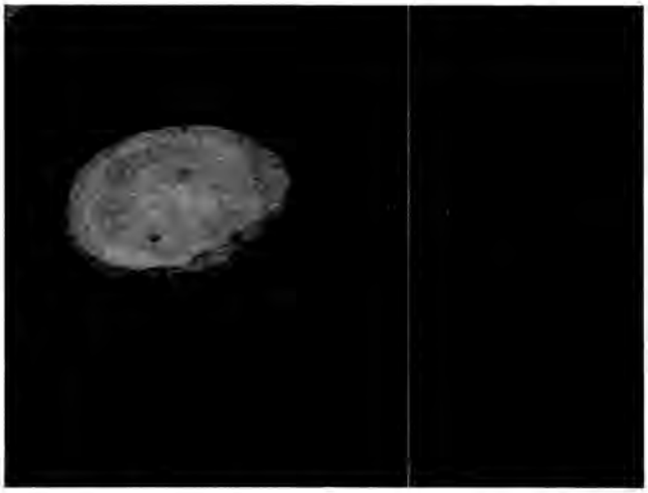

Fig. 7. Drop-Test Specimens--Cement (left) Versus Light-Weight, Reinforced Vermiculite-Concrete (right) Used for Solidifying Sodium Sulfate Liquid.

Fig. 8. Drop-Test Specimens--Cement (left) Versus L:ight-Weight, Reinforced Vermiculite-Concrete (right) Used for Solidifying Sodium Nitrate Liquid.

void space in drums or remote-handled TRU containers).

REFERENCES

1. Code of Federal Regulations, U.S. National Archives, Volume 10, Part 61, Section 71.73, p. 178, (Jan. 1989).
2. D.A. Edling, D.R. Hopkins, and R.L. Williams, "DOE Evaluation Document for DOT 7A Type A Packaging", MLM-3245 or DOE/DP/00053-H1, March 1987, p. A-17.
3. "TRU Waste Certification Compliance Requirements for Remote-Handled Wastes for Shipment to the Waste Isolation Pilot Plant", WIPP-DOE-158-Rev. 1, Jan. 1989, p.17. Also, SAR data sheet information obtained from WIPP on the TRUPACT transport overpack.

TABLE VI
Weight Characteristics of Solidified Liquid Waste

Sample No.	Waste liquid description	Cement or concrete description	Density (kg/L)	Filled drum weight (kg)	Liquid waste content (L)
1	Water	Construction	2.30	499	57 to 75
2	Sat. sodium sulfate (20%)	Cement	2.10	458	151
3	Sod. nitrate (20%)	Cement	2.08	454	136
4	Sod. nitrate (18%)	Cement	2.07	451	132
5	Sat. sodium sulfate (20%)	Reinforced vermiculite-concrete	1.30	293	134
6	Sod. nitrate (20%)	Reinforced vermiculite-concrete	1.36	304	129
7	Sod. nitrate (18%)	Reinforced Fibermesh-concrete	1.25	283	110

TABLE VII
Strength Characteristics of Solidified Liquid Waste

Sample No.	Waste liquid description	Cement or concrete description	Compression strength (kg/cm^2)	Impact strength (J/cm^2)
1	Water	Construction	176	0.30
2	Sat. sodium sulfate (20%)	Cement (no aggregate)	288	0.45
3	Sodium nitrate (20%)	Cement (no aggregate)	134	0.45
4	Sodium nitrate (18%)	Cement (no aggregate)	136	0.30
5	Sat. sodium sulfate (20%)	Reinforced vermiculite-concrete	15	1.05
6	Sodium nitrate (20%)	Reinforced Vermiculite-Concrete	10	0.90
7	Sodium nitrate (18%)	Reinforced Fibermesh-concrete	13	0.60