Recycling Contaminated Spent Blasting Abrasives in Portland Cement Mortars

BRYAN K. SALT, ANDRÉ G. GARNER, DAVID W. FOWLER, RAYMOND C. LOEHR, AND RAMON L. CARRASQUILLO

Use of abrasive blasting to remove paint containing lead, cadmium, and chromium from steel bridges is producing contaminated spent blasting abrasives that may be classified by the Environmental Protection Agency as hazardous, because of their toxicity. Transportation and disposal of spent abrasives is difficult and costly. A potentially inexpensive and practical solution is to recycle contaminated spent blasting abrasives at the construction site in an environmentally safe manner using solidification and stabilization technology. A further benefit of recycling spent blasting abrasives is that there is no need to use landfills or hazardous waste disposal sites. The use of portland cement to solidify and stabilize spent abrasives to produce usable construction material is investigated. Recommendations provided to the Texas Department of Transportation were applied at the Rainbow Bridge in Beaumont, Texas, where the mix designs were used successfully to recycle more than 3,000 55-gal drums of spent blasting abrasives produced at the site. Recycling involved producing concrete blocks that were subsequently used as filler material in the dolphins around the bridge piers.

Use of abrasive blasting to remove lead-based paints results in contaminated spent blasting abrasives that may be classified as hazardous by the Environmental Protection Agency (EPA). Contaminated spent blasting abrasives are considered hazardous waste if they exhibit a "characteristic of toxicity," as defined in the Resource Conservation and Recovery Act. If the Toxicity Characteristic Leaching Procedure (TCLP) leaching of lead, cadmium, or chromium is more than the maximum levels set by EPA, the material must be treated and rendered nonhazardous before land disposal. A preferable alternative to land disposal, however, would be to recycle the waste material in an environmentally sound application at the construction site.

To produce a usable construction material from spent blasting abrasives, the solidification/stabilization (S/S) process must satisfy environmental and construction concerns. The S/S process must be able to render the spent blasting abrasives nonhazardous by reducing the leaching of the lead, cadmium, and chromium to levels below the maximum levels set by EPA. At the same time, the S/S process must be able to produce an end product of adequate strength and durability.

Contaminants resulting from abrasive blasting of lead-based paints can cause problems for portland cement S/S systems. Lead can act as a retarder on the hydration of cement, causing longer set times and lower strengths (*1*). Aluminum, although not considered toxic, is present in many paints. It reacts with the cement to produce hydrogen gas, resulting in lower strength and more permeable mortars.

B. Salt, A. Garner, Hunt & Joiner, Inc., 4300 N. Central Expressway, Suite 206, Dallas, Tex. 75206. D. Fowler, R. Loehr, R. Carrasquillo, Department of Civil Engineering, University of Texas at Austin, 10100 Burnet Road, #18B, Austin, Tex. 78578.

This study addresses the effectiveness of portland cement mortars in rendering spent blasting abrasives nonhazardous through the S/S processes and in recycling the spent blasting abrasives in portland cement mortars for use as a construction material.

EXPERIMENTAL PROGRAM

Introduction

More than 160 different portland cement mortar mixes have been tested to investigate the S/S capabilities of portland cement mortars on spent blasting abrasives. The spent material either was spent blasting sand, spent blasting dust, or a combination of the two. The main elements of concern found in the spent material were lead, chromium, cadmium, and aluminum.

The test variables to be studied were

- Water/cement (W/C) ratio;
- Cement content;
- Amount of fly ash;
- Amount of silica fume;
- Dosage of superplasticizer;
- Dosage of calcium nitrite as an accelerator;
- Spent material type, composition, and amount;
- Strength gain over time;
- Leaching of lead, chromium, and cadmium as per TCLP; and
- Permeability.

Materials

Most S/S mixes were made with spent blasting sand, which was processed in several forms: separated spent blasting sand and separated spent blasting dust. Each results from spent blasting sand that has been run through a particle separator after blasting. A particle separator isolates larger sand particles to be reused for further blasting and removes the dust and paint chips to waste barrels. The separated spent blasting sand and spent blasting dust can be combined in the desired proportions for recycling in concrete. Unseparated spent blasting sand/dust is spent blasting sand that has not been run through a particle separator before being placed in waste barrels. Spent blasting sands have a fine gradation because of the blasting process. Fineness moduli for the spent blasting sands used in this study ranged from 2.25 to 2.39.

Except for the spent blasting abrasives, all other materials used in the study are commercially available and currently used in the production of portland cement concrete in Texas. Materials used

TABLE 1 TCLP and TCA Results for Spent Blasting Abrasives

Material Type and Origin	TCLP (mg/L)				TCA (mg/kg)				% Lead
	Pb	Cr	Cd	Al	Pb	Cr	Cd	Al	by wt.
Separated Spent Blast Sand A Rainbow Bridge Barrel # 1	2.02	0.58	0.57	0.54	367.0	54.5	15.5	192.5	0.04
Separated Spent Blast Sand B Rainbow Bridge Barrel # 2	1.13	1.42	0.53	1.38					
Separated Spent Blast Dust A Rainbow Bridge Barrel # 1	9.48	5.36	1.07	2.54	2896.0	724.5	68.0	1946.0	0.29
Separated Spent Blast Dust B Rainbow Bridge Barrel # 2	1.14	9.51	1.08	4.95					
Unseparated Spent Blast Sand/Dust A Rainbow Bridge Barrel # 1	0.48	2.09	0.62	0.56	981.5	389.5	34.0	711.0	0.10
Unseparated Spent Blast Sand/Dust B Odessa Bridge Barrel # 1	1.33	0.56	0.29	0.65	125.4	52.9	11.9	688.7	0.01

include Type I/II portland cement, siliceous river sand with a bulk specific gravity (BSG) at SSD of 2.58 and an absorption capacity of 1.44 percent, an ASTM Class C fly ash with a BSG of 2.58, a condensed silica fume with a BSG of 2.20, a high-range water reducer, and a calcium nitrite accelerator.

Table 1 presents the results of TCLP and total constituent analysis (TCA) for the spent blasting abrasives used in the project. TCLP results are given in terms of milligrams of contaminant per liter of acid leachant, and TCA results are given in milligrams of contaminant per kilogram of spent blasting abrasives. The percentage of lead by weight in the spent blasting abrasives is also indicated.

Mix Proportions

Tables 2–6 contain detailed information on the specimen designations and corresponding mix proportions for selected mixes. When mineral admixtures were used, fly ash was used as a volumetric replacement for portland cement in the amount of 30 percent, and silica fume was used in addition to the portland cement in the amount of 12 percent of the weight of portland cement. All mix proportions were based upon a cubic-yard batch of concrete, less the volume of coarse aggregate.

TABLE 2 Proportions for Mixes with Separated Spent Blast Sand A

Mix #	Cement (kg)	Concrete Sand (kg)	Blast Sand (kg)	W/C Ratio by wt.
1	213	499	0	0.38
2	213	299	200	0.37
3	213	100	399	0.40
4	320	499	0	0.35
5	320	299	200	0.37
6	320	100	399	0.38

TABLE 3 Proportions for Mixes with Separated Spent Blast Dust A

Mix #	Cement (kg)	Concrete Sand (kg)	Blast Dust (kg)	W/C Ratio by wt.
7	213	499	25	0.40
8.	213	499	175	0.57
9	320	499	25	0.38
10	320	499	175	0.50

1 kg = 2.205 lbf

Mix Procedure

All batches were mixed using the following procedure:

- All raw materials were weighed to the nearest one-tenth of a pound;
- The mixer was charged with the dry materials, followed by mixing for 10 sec;
- The water and superplastisizer were added, followed by mixing for 3 min;
- The batch was allowed to rest without mixing for 2 min;
- If needed, additional superplastisizer was added to achieve the required workability; and
- The batch was mixed for 3 min more.

Mixes containing mineral admixtures normally required a slightly longer mixing time for adequate distribution of the fine particles.

Casting and Curing

Specimen molds were filled in two equal layers and vibrated on a vibrating table for 20 sec according to ASTM C192-88. Specimens were then finished using aluminum trowels.

Curing consisted of placing specimens under wet burlap and polyethylene for the first 24 hr after casting, per ASTM C192-88, after which they were removed from the molds and placed in a moist curing room. Mixes taking longer to set than 24 hr because of lead retardation were kept under the wet burlap and polyethylene until they set, at which time they were removed from the molds and placed in a moist curing room. Mixes that had not set within 7 days of curing were discarded. The moist curing room was kept at 23°C and 100 percent relative humidity until testing, in conformance with ASTM C511-85.

Testing Procedures

Workability of fresh mortar mixes was measured according to ASTM C109-87. A targeted workability was established on the basis of the control mixes, and all subsequent mixes were batched to have similar workability, as indicated by the flow table test.

Compressive strength of hardened mixes was determined using cylinders 76 mm (3 in.) in diameter and 152 mm (6 in.) tall, which

TABLE 4 Proportions for Mixes with Unseparated Spent Blast Sand/Dust A

Mix #	Cement (kg)	Blast Sand/Dust (kg)	HRWR[a]	Fly Ash (kg)	Silica Fume (kg)	W/C Ratio by wt.
11	213	499	15.8	0	0	0.35
12	213	499	9.4	0	0	0.35
13	320	499	7.8	0	0	0.35
14	320	499	6.2	0	0	0.35
15	320	499	14.2	0	38	0.35
16	320	499	7.8	96	38	0.35
17[b]	320	249	7.8	0	0	0.35

[a] In mL per kg of cement
[b] Includes 249 kg of Concrete Sand
1 kg = 2.205 lbf

TABLE 5 Proportions for Mixes with Separated Spent Blast Sand B and Separated Spent Blast Dust B

Mix #	Cement (kg)	Blast Sand (kg)	Blast Dust (kg)	HRWR[a]	Calcium Nitrite (L/m^3)	Silica Fume (kg)	W/C Ratio by wt.
18	320	499	0	0.0	0	0	0.35
19	320	499	25	12.3	0	0	0.35
20	320	499	75	25.5	0	0	0.35
21	320	499	125	39.6	0	0	0.35
22	320	499	0	0.0	9.9	0	0.35
23	320	499	25	1.7	9.9	0	0.35
24	320	499	75	5.5	9.9	0	0.35
25	320	499	125	11.2	9.9	0	0.35
26	320	499	0	2.4	0	38	0.35
27	320	499	25	6.3	0	38	0.35
28	320	499	75	17.4	0	38	0.35
29	320	499	125	21.1	0	38	0.35

[a] In mL per kg of cement
1 kg = 2.205 lbf

TABLE 6 Proportions for Mixes with Unseparated Spent Blast Sand/Dust B

Mix #	Cement (kg)	Blast Sand/Dust (kg)	HRWR[a]	Calcium Nitrite (L/m^3)	Silica Fume (kg)	W/C Ratio by wt.
30	320	499	7.8	0	0	0.35
31	320	499	10.8	0	38	0.35
32	320	499	7.8	9.9	0	0.35

[a] In mL per kg of cement
1 kg = 2.205 lbf

were tested according to ASTM C39-79, at 7, 28, and 90 days. Cylinders were capped using unbonded neoprene caps inside steel restraining rings.

Permeability of hardened mixes was determined according to AASHTO T-277, Rapid Determination of the Chloride Permeability of Concrete, at 28 days with the following exceptions:

1. Tests were conducted on 102-mm (4-in.) diameter mortar cylinders instead of 95-mm (3.75-in.) diameter concrete core specimens (*2*).
2. Two 51-mm (2-in.) thick specimens were cut from the interior of each cylinder instead of using two specimens cut from the ends of a cored specimen (*2*).
3. Specimens were kept saturated in a sealed vacuum for an hour after evacuation, in lieu of a forced vacuum (*2*).

TCLP testing was performed as per 40 CFR 261, Appendix II-Method 1311 (7-1-90 Edition) at 7 or 28 days or both. TCLP is designed to simulate the leaching potential of waste disposed of in a municipal landfill. The waste is subjected to an acetic acid solution to simulate the organic acids produced at a landfill during decomposition of organic material in refuse. TCLP concentration limits have been set for 25 organic compounds, eight metals, and six pesticides. Metals of concern in this study are lead, cadmium, and chromium, as they are used in the manufacturing of paints and pigments. EPA's TCLP concentration limits for these three metals are indicated in Table 7.

TEST RESULTS

Compressive Strength and Rapid Chloride Ion Permeability

The compressive strengths and rapid chloride ion permeabilities for the S/S mixes detailed in tables 2–6 are presented in Table 8. Com-

TABLE 7 7-Day TCLP Leaching Results for Selected Mixes

Mix #	Lead (mg/L)	Chromium (mg/L)	Cadmium (mg/L)
1	0.09	0.46	0.18
2	0.09	0.52	0.15
3	0.13	0.54	0.12
4	0.12	0.39	0.11
5	0.10	0.42	0.15
6	0.02	0.44	0.16
7	0.10	0.59	0.17
8	-	-	-
9	0.07	0.56	0.16
10	0.05	1.00	0.16
11	-	-	-
12	-	-	-
13	-	-	-
14	-	-	-
15	0.07	2.36	0.13
16	0.04	4.15	0.13
17	0.06	1.07	0.14
18	0.09	2.17	0.04
19	0.12	2.16	0.07
20	-	-	-
21	-	-	-
22	0.18	1.72	0.15
23	0.19	1.92	0.19
24	-	-	-
25	-	-	-
26	0.08	1.87	0.06
27	0.07	1.92	0.09
28	0.08	1.79	0.10
29	0.12	1.77	0.09
30	0.17	0.67	0.11
31	0.07	0.79	0.03
32	0.00	0.53	0.05
EPA Limits	5.00	5.00	1.00

- Not tested due to no set

pressive strength is given as the average strength of two companion cylinders at 7, 28, and 90 days, and permeability is given as the average chloride ion permeability of four companion specimens cut from two cylinders at 28 days. Unless otherwise noted, mixes set within 24 hr of mixing.

TCLP Leaching Results

The TCLP leaching results of the S/S mixes detailed in Table 2–6 are presented in Table 7 along with the EPA TCLP leaching limits. Leachability is given as the average of TCLP leaching values from three 50-mg samples tested at 7 days. TCLP leaching tests were conducted for lead, chromium, and cadmium (*3*).

DISCUSSION OF RESULTS

All raw materials used in the study were characterized by TCLP and TCA. That information is necessary to determine how much background contamination exists in the portland cement, water, or mineral admixtures, as well as the contamination level of the spent blasting abrasive.

The effectiveness of portland cement S/S systems depends greatly on the contamination level of the spent blasting abrasives. The contamination level of the spent blasting abrasives could vary greatly along the span of a bridge because of differences in paint systems. Particle size of pulverized paint also affects portland cement mortar. As a result, characterization of the spent blasting abrasives for each job is important in determining the most suitable mix design.

Likewise, because of the variability of background contamination of portland cement, water, and chemical and mineral admixtures, the characterization of these materials is necessary. If the materials contain large amounts of contaminants, their use should be questioned, and a material with less contaminants might have to be used.

The effect of contamination level on set times is an important consideration; it can affect the success of portland cement S/S systems. In summary, the effect of contamination level on set times can be stated as follows: the higher the amount of contamination in a portland cement mortar, the longer the set time; the higher the cement content, the shorter the set time. As reflected in Table 5, Mixes 18–21 had an increasing spent blasting dust content which effectively increased their level of contamination. As Table 8 indicates, set times increase the greater the spent blasting dust content. Mixes with the higher dust contents were not set within 7 days. The mixes with higher cement contents set faster, apparently because of a lower lead/cement ratio when the amount of spent blasting abrasives is constant.

Silica fume and calcium nitrite effectively reduced the set times of the mixes. Mixes 22–25 were identical to Mixes 18–21, except

TABLE 8 Compressive Strength and Rapid Chloride Ion Permeability for Selected Mixes

Mix #	Average Compressive Strength (MPa)			Permeability[a]	Set Time
	7 Day	28 Day	90 Day	coulombs	
1	43.2	50.5	56.7	7460	
2	21.8	28.2	28.8	8110	
3	20.2	18.7	25.3	N/A	
4	60.6	70.5	77.1	3300	
5	37.0	39.0	47.5	8100	
6	31.4	33.9	29.6	8410	
7	14.2	17.5	19.8	7460	
8	0.0	0.0	0.0	N/A	NO SET
9	20.6	27.5	26.9	5620	
10	8.7	10.8	10.3	8810	
11	0.0	0.0	0.0	N/A	NO SET
12	0.0	0.0	0.0	N/A	NO SET
13	0.0	0.0	0.0	N/A	NO SET
14	0.0	0.0	0.0	N/A	NO SET
15	15.4	21.0	21.0	5270	
16	4.3	18.5	19.9	10070	
17	23.1	27.6	32.4	10080	
18	21.5	21.0	32.0	11130	SET 3D
19	8.0	5.3	5.2	16460	SET 6D
20	0.0	0.0	0.0	N/A	NO SET
21	0.0	0.0	0.0	N/A	NO SET
22	22.1	27.1	33.0	21110	SET 1D
23	16.1	23.0	21.6	18260	SET 2D
24	0.0	0.0	0.0	N/A	NO SET
25	0.0	0.0	0.0	N/A	NO SET
26	11.7	16.9		4450	SET 1D
27	13.7	19.4		6990	SET 1D
28	18.0	25.9		6450	SET 1D
29	10.9	14.1		11790	SET 4D
30	11.9	16.3	15.4	12800	
31	13.9	16.1	18.3	2450	
32	43.2	54.5	58.7	6880	

[a]28-Day Test Age
N/A - Not applicable due to no set
1 MPa = 145.0 lbf/in^2

that the former contained a 9.9 L/m^3 (2 gal/yd^3) dosage of calcium nitrite as an accelerator. The calcium nitrite effectively reduced set times for mixes with lower dust contents; however, mixes with the higher dust contents still would not set within 7 days. Silica fume was most effective in reducing set times; its use resulted in the higher dust content mixes (Mixes 26–29) setting within 7 days. Future research will study the effect of other accelerators, such as calcium chloride and sodium silicate, on the set times of mixes.

The effect of contamination level on compressive strength can be drawn from Figures 1–3; by observing: the more spent blasting abrasive used instead of clean concrete sand, the lower the compressive strength; the greater the cement content, the higher the compressive strength; and, the lower the W/C ratio, the higher the compressive strength. Silica fume and calcium nitrite generally were found to increase compressive strength.

The effect of contamination level on permeability can be summarized by referring to Figures 4–6, which reflect that the lower the W/C ratio and the higher the cement content, the lower the permeability. Mixes containing silica fume, fly ash, and calcium nitrite had lower permeabilities. Finally, the greater the clean fine-aggregate replacement with spent blasting abrasives, the higher the permeability.

The effect of composition on TCLP results is reflected in Figures 7 and 8. The higher the W/C ratio, the higher the leaching of contaminants; the higher the cement content, the lower the leaching of contaminants. Mixes containing silica fume showed lower leaching. Those trends also depend on the background composition of the binder materials, such as portland cement, clean fine aggregate, mix water, and mineral admixtures.

The compressive strength effect on TCLP results can be observed in the trend toward decreased leaching of contaminants with in-

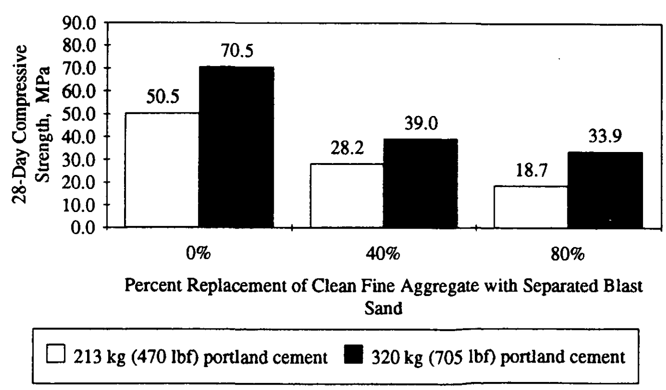

FIGURE 1 28-day compressive strength versus percent replacement of clean fine aggregate for separated Sand A mixes.

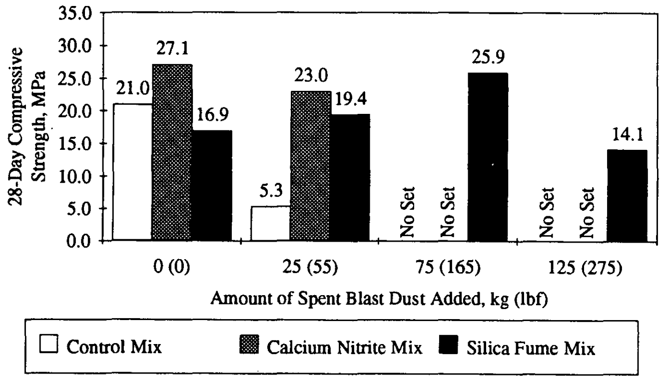

FIGURE 2 28-day compressive strength for separated Sand B/Separated Dust B mixes.

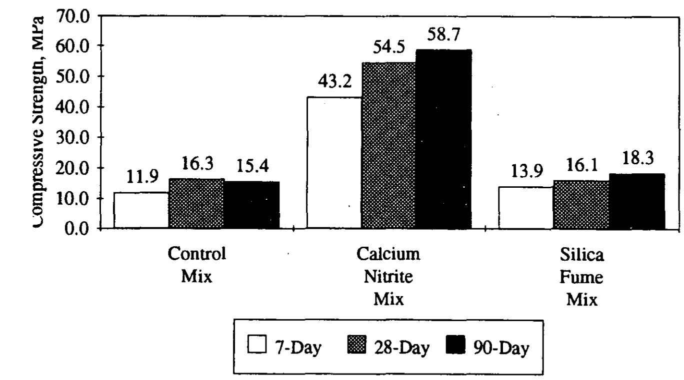

FIGURE 3 Compressive strength for unseparated Sand B mixes.

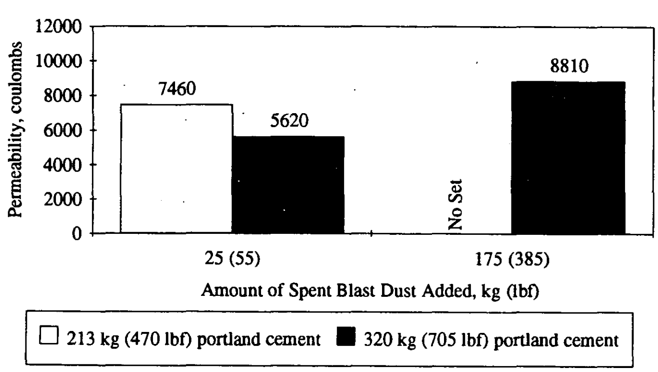

FIGURE 4 Permeability versus amount of spent blast dust for Separated Dust A mixes.

creased compressive strength. However, in many mixes, no correlation is observed. Two variables that affect compressive strength, W/C ratio and cement content, are the most important factors affecting TCLP leaching. Lower W/C ratios and higher cement contents produce mixes with higher compressive strengths and lower contaminant leaching.

The effect of permeability on compressive strength is, in general, that the compressive strength of the S/S matrices decrease as permeability of the matrices increases, regardless of the type of spent blasting abrasives or if whether chemical or mineral admixtures are used.

Factors contributing to the success of a portland cement mortar are the mixing sequence and the time used during the batching procedure. The importance of mixing sequences and times was determined from laboratory observations. Stabilized mortar mixes, batched using the following mixing procedure, were the most uniform and gave the most predictable results. The mixing procedure is as follows: (*a*) mix most of the dry materials first, (*b*) add the water and chemical admixtures, (*c*) add the remaining dry material and (*d*) continue mixing. As a rule of thumb, S/S mixes should be mixed approximately two to three times—as long as ordinary concrete and mortar mixes. S/S mixes that were mixed for short periods of time were not uniform and had pockets of unmixed material. Pockets of unmixed material either had an accelerated or a delayed set, depending on the mix constituents in the areas of concentration.

FIELD APPLICATION

Recommendations based on this study were provided to the Texas Department of Transportation for use at the Rainbow Bridge in Beaumont, Texas (*4*). Table 9 gives the mix proportions recommended for recycling the spent blasting abrasives generated at this particular site.

The recommendations were followed successfully in recycling more than 3,000 55-gal drums of spent blasting sand produced at

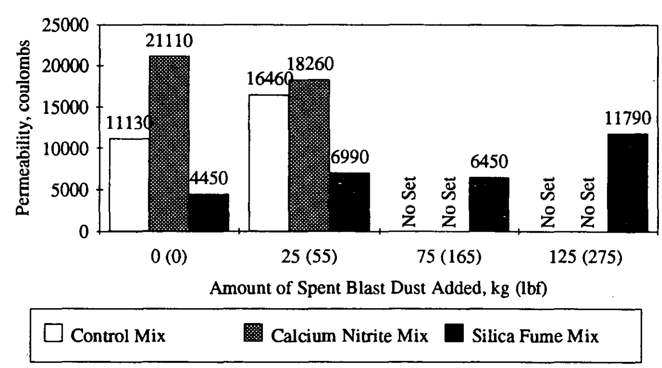

FIGURE 5 Permeability for Separated Sand B/Separated Dust B mixes.

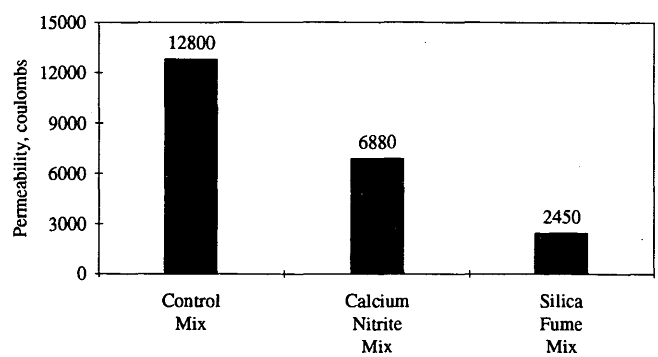

FIGURE 6 Permeability for Unseparated Sand B mixes.

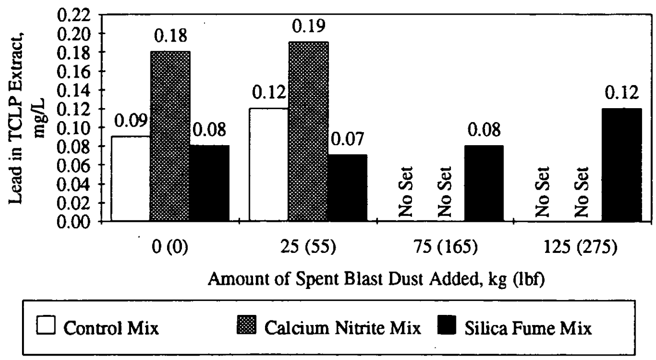

FIGURE 7 TCLP lead leaching for Separated Sand B/Separated Dust B mixes.

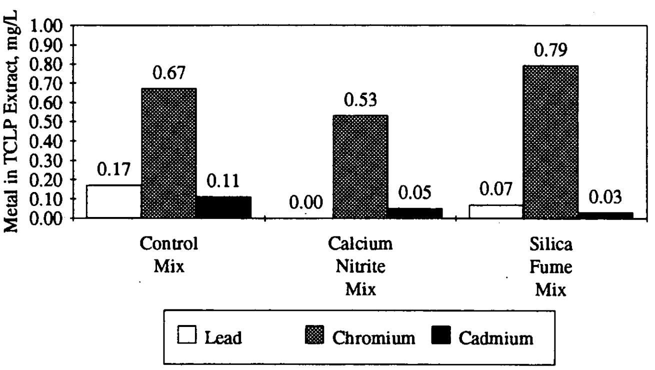

FIGURE 8 TCLP leaching for Unseparated Sand/Dust B mixes.

this site. The mix was used to produce approximately 50,000 12-in. square by 6-in. thick blocks. The blocks were placed as filler material in dolphins around the bridge piers to protect them from ship collisions.

The mix designs not only provided an environmentally sound way to recycle the spent blasting abrasives as a construction material but also resulted in a cost savings to the Texas Department of Transportation. Future research will be to acquire field specimens for compressive strength, permeability, and TCLP testing.

CONCLUSIONS

The following conclusions are made on the basis of this study:

- A portland cement-based S/S system that has adequate compressive strength and permeability and meets EPA's and the Texas Department of Transportation's environmental guidelines can be produced using the contaminated spent blasting abrasives investigated in this study.
- The most important factors governing TCLP leaching, compressive strength, and permeability are W/C ratio and cement content. The lower the W/C ratio and the higher the cement content, the lower the leaching and the higher the compressive strength, regardless of the admixtures used.
- The higher the contamination level of an S/S mix, the longer the set times and the lower the compressive strength. Silica fume and calcium nitrite are effective in reducing set times and increasing compressive strength.
- S/S mixes exhibiting lower permeability also had lower TCLP leaching, not because of the permeability of the matrix, but because the factors that affect leaching the most—because of W/C ratio and cement content—also affect permeability. Silica fume effectively reduces permeability and therefore TCLP leaching.
- The trend is toward decreased leaching with increased compressive strength; however, in many mixes, no such correlation was observed.
- Setting times did not affect TCLP leaching or compressive strength. S/S mixes with a delayed set because of lead retardation exhibited adequate strength and leaching characteristics at later ages.
- Mixing sequence and times are important for the success of S/S systems. Best performance was obtained when the majority of the dry components were mixed thoroughly before adding water or chemical admixtures.
- As shown in the Rainbow Bridge project, portland cement mortars can be effective in treating and recycling spent blasting abrasives, as an alternative to land disposal, thereby reducing the burden to landfills and resulting in a significant cost savings compared with disposal.

TABLE 9 Recommended Mix Proportions for Rainbow Bridge Spent Abrasive Recycling

Cement	320 kg (705 lbf)
W/C ratio	0.35
Superplastisizer	13.7 mL/kg (21 oz./cwt)
Silica Fume	12% by weight addition to cement
Spent Blasting Sand	499 kg (1100 lbf)

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