

Variability of field solidified waste

Julia A. Stegemann ^{*}, Robert J. Caldwell, Caijun Shi

Water Technology International Corporation, Operator of the Wastewater Technology Centre and the Canadian Clean Technology Centre, P.O. Box 5068, Burlington, Ont., L7R 4L7, Canada

Abstract

The properties of solidified waste prepared in the field can be anticipated to be more variable than those of solidified samples prepared in the laboratory, because of the greater difficulty in controlling parameters such as untreated waste and binder homogeneity, accuracy of dosage, mixing efficiency, changes in handling characteristics caused by scale-up, etc. However, there is little information available regarding the effect of field variability on solidified waste properties. In a field trial conducted by the Wastewater Technology Centre it was found that the proportions of the waste (electric arc furnace dust) and binder (activated blast furnace slag) could be controlled within 2%, expressed as a fraction of the mix. Comparison of comprehensive physical and chemical test results for laboratory and field solidified specimens of electric arc furnace dust showed that the physical properties of the field solidified material were sensitive to changes in water addition. Chemical properties and leachability were most affected by changes in pH and acid neutralization capacity. However, both physical and chemical properties remained within the desired range. © 1997 Elsevier Science B.V.

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1. Introduction

The properties of a solidified waste are often subjected to detailed characterization prior to field implementation of the technology. Extensive testing may be performed when developing a suitable solidification formulation, and to demonstrate to regulatory or other authorities that solidification has been effective in improving physical handling characteristics, or reducing leachability of contaminants, or both. Of necessity, this testing is performed on solidified samples that have been prepared in the laboratory. In the laboratory, it is possible to homogenize materials thoroughly, weigh them out with

^{*} Corresponding author.

great precision, mix them together efficiently, and compact them carefully into molds to form uniform solidified specimens.

By contrast, in field-scale solidification, there are a tremendous number of potential sources of variability in the solidified product. For instance, it is seldom possible to completely homogenize the entire mass of waste to be treated. Binder materials are frequently blended off-site, using large-scale equipment with a limited accuracy and mixing efficiency, and then transported to the site of solidification. Segregation may occur during transport. Whereas laboratory processing can usually be performed in 1 batch, field processing must occur either in a series of small batches, or in continuous mode; both will result in greater heterogeneity. The accuracy of dosing of the waste, binder material(s) and water to the mixer is also limited, and the efficiency of mixing is dependent on the characteristics of the materials being mixed, and the type of mixer used. Consequently, it is inevitable that the characteristics of a solidified product prepared in the field will not be as uniform as those of specimens prepared in the laboratory. However, there is little information available regarding the magnitude of the variability that can be expected in the field. This is one of the factors that make it difficult to use laboratory tests to predict the characteristics of a final field-solidified product. This uncertainty associated with prediction of field properties has hindered acceptance of solidification as a viable treatment technology by regulators and waste generators.

As part of a field validation study of their Proposed Evaluation Protocol for Cement-based Solidified Wastes [1,2], researchers at the Wastewater Technology Centre (WTC) performed a variety of physical and chemical tests on solidified waste samples collected during field solidification. Common statistical parameters have been used to express the variability in these properties, in order to provide information regarding the uniformity which can be expected of field-solidified products.

2. Approach

2.1. Field solidification

The field solidification was performed on 65 tonnes of an electric arc furnace (EAF) dust from specialty steel production, which is considered both a listed hazardous waste and leachate toxic in many jurisdictions. Analysis of seven 100 g samples taken at random from approximately 100 supersacks of the untreated EAF dust at the solidification site yielded the contaminant concentrations summarized in Table 1.

The EAF dust was solidified using a formulation containing blast furnace slag, hydrated high calcium lime, silica fume, and sodium metasilicate developed at WTC [3]. To simplify dosage and mixing of additives at the field site, the ground blast furnace slag, hydrated lime and silica fume were pre-blended off-site in the desired proportions using a ribbon blender, and transported to the site in a pneumatic trailer. The characteristics of the individual binder components and quality control testing of the blending process has been reported elsewhere [4]. Table 2 shows a summary of the batch blending records.

Table 1
Summary of composition of electric arc furnace dust (based on analysis of 7 samples)

Parameter	Average concentration (mg kg ⁻¹)	Standard deviation
Boron	783	53
Cadmium	131	21
Chromium	39 100	9780
Copper	10000	1400
Lead	15000	1340
Mercury	1.5	0.83
Zinc	66 000	4880

The sodium metasilicate activator, with a molar ratio of Na₂O to SiO₂ of 1:1.11, was transported to the site as a 12.5% solution in a tanker truck. At the field site, the concentration of the sodium silicate solution used in solidification was adjusted depending on the water consumption of the mix and the atmospheric temperature, which ranged from -2.3 to +25.5°C.

Mixing of the solidified waste was performed using the Shaw-Eurocan Environmental Inc. (SHEEINC) mobile treatment system. The SHEEINC unit was composed of a central high shear concrete mixer, surrounded by hoppers on load cells for each of the components of the mix. For each batch, the mass of EAF dust dosed to the mixer was used to calculate and weigh in appropriate dosages of first binder and then sodium silicate solution. Although the SHEEINC unit was equipped with an automatic controller, it could be used for only 97 of the 414 batches prepared. The remaining batches were prepared manually. Both the automatic and manual batch masses were recorded on a spreadsheet.

Mixing took place in batches with a total mixed volume of approximately 0.15 m³ each. The components were mixed for approximately 3 min before being discharged to a piston pump, which transported the mixture a distance of approximately 50 m to a specially prepared experimental landfill cell [2]. As several batches were required to fill the volume of the pipe, intermixing of the batches occurred during pumping. A pencil vibrator was used to compact the material upon discharge into the cell.

14 samples of solidified waste for quality control testing were taken from the discharge in the landfill cell at random intervals over the 21 days of solidification. The

Table 2
Summary of composition of blended dry additives (based on blending records for a total of 33 batches)

Blend component		Blast furnace slag	Hydrated lime	Silica fume
Total mass (tonne)		42.8	17.1	5.1
% of dry blend	Average	65.87	26.30	7.83
	Range ^a	65.77–66.01	26.17–26.49	7.67–7.98
	Standard deviation ^a	0.06	0.06	0.06
Design blend (%)		65.8	26.3	7.9

^a Batch-to-batch variation.

sample size ranged from 1.5 to 15 l. Field quality control consisted of measurement of bulk density, moisture content, and slump [5]. Specimens were also molded for curing in the WTC laboratory. The molded specimens were enclosed in double plastic bags and stored underwater in sealed pails water in sealed at a mean field temperature of 11°C from 1 to 21 days before being transported to the WTC laboratory.

2.2. Testing of solidified waste

After 7 months of moist curing in the WTC laboratory at 22°C, 10 of the test samples produced in the field were subjected to the WTC Proposed Evaluation Protocol for Cement-based Solidified Wastes to evaluate their characteristics, and compare them with those of the design mix prepared in the laboratory (which were evaluated after 56 days of curing). The WTC protocol examines basic engineering properties of solidified wastes, and chemical and physical immobilization of contaminants in 3 levels of testing (Levels 0, 1 and 2). Detailed methods for Level 0 and Level 1 tests are available in an Environment Canada publication [6]. The test methods and properties which they are intended to measure are discussed briefly here.

2.2.1. Level 0: basic information regarding the process and matrix

2.2.1.1. Bulk density. A specimen of known volume is weighed and density is reported as mass/volume. The result is used in calculations for mass and volume changes, porosity and saturation.

2.2.1.2. Moisture content. A sample is dried to constant mass at 60°C. The change in mass divided by the mass of the wet sample corresponds to the moisture content. Moisture content is used to calculate porosity and saturation, and bears a relationship to resistance to weathering and leaching.

2.2.1.3. Solids specific gravity. The solids density of a sample is determined by measuring the volume of helium displaced by a sample of known weight, and compared with the density of water to calculate a solids specific gravity value. The result is used in calculations of porosity and saturation.

Bulk density and moisture content were measured in triplicate for the design formulation and each of the 10 archived field samples; specific gravity was measured in duplicate.

Bulk concentrations of the contaminants of concern are also important basic information regarding the solidified waste. Duplicate analyses of the 10 archived field samples were performed. Analytical methods for these are discussed later in this paper.

2.2.2. Level 1: chemical immobilization

2.2.2.1. Equilibrium extraction. A sample of finely ground waste is rotated end-over-end with distilled water at a liquid-to-solid ratio of 4:1 for a 7 day period. Analysis of the leachate for the contaminants of interest indicates their solubility in the chemical

environment prevailing in the waste form (in mg l^{-1}) and provides an estimate of the pore composition of an initial undiluted leachate, i.e., the initial leachate concentration.

2.2.2.2. Amount available for leaching. A sample of finely ground waste is rotated end-over-end with acetic acid buffered to pH 5 with 1 M sodium acetate for 24 h. The amount of contaminant released under these harsh conditions (expressed as mg kg^{-1} of wet solid) approximates the amount available for leaching in the long term under worst case conditions.

2.2.2.3. Acid neutralization capacity. Sub-samples of finely ground waste are extracted using a range of nitric acid additions for 48 h. The pH measurements of the extracts can be plotted as a titration curve which is used to evaluate the ability of the solidified waste to neutralize acid. Acid neutralization capacity of a solidified waste is important both for preventing deterioration of the solidified waste matrix, and immobilizing many metal contaminants.

The equilibrium extraction and amount available for leaching test were performed in triplicate and a single acid neutralization capacity curve was determined for the design formulation and each of the 10 archived samples.

2.2.3. Level 2: physical encapsulation

2.2.3.1. Dynamic leaching test. A solidified waste specimen of known geometrical surface area is immersed in distilled water at a specified leachant volume to specimen surface area ratio. The leachant is replaced at calculated intervals, and the leached quantities of the contaminants of interest in each interval are used to calculate a leachability index (L) which is an expression of the contaminant mobility in the matrix under the prevailing leaching environment. Under certain conditions, the test measures diffusivity of contaminants through the waste matrix. This test is an American Nuclear Society test (ANSI/ANS 16.1 [9]).

2.2.3.2. Hydraulic conductivity. In this test a hydraulic head is applied to a sample confined in a flexible rubber membrane in a triaxial cell. Using Darcy's law, the hydraulic conductivity may be calculated from the time required for a measured head loss. In the field, the hydraulic conductivity of a solidified waste relative to that of the surrounding geology will determine the relative importance of advection and diffusion within the monolith. ASTM D 5084 was used, with the difference that a maximum hydraulic gradient of 100 was applied to samples with a hydraulic conductivity lower than 10^{-9} m s^{-1} .

2.2.3.3. Unconfined compressive strength. Following ASTM C 109 (but using a specimen of solidified waste in place of a mortar specimen) a laterally unconfined specimen is axially loaded until failure using a compression machine. The unconfined compressive strength indicates the ability of a solidified waste monolith to maintain its physical integrity when subjected to stresses imposed under disposal conditions. This

test is performed on dry test samples and on test samples which have been immersed in water for a period of 7 days prior to testing.

2.2.3.4. Freeze–thaw weathering. A specimen of solidified waste is subjected to 12 successive cycles of freezing at -20°C for 24 h, followed by thawing in water at room temperature for 24 h. The mass loss of the specimen after each cycle is determined and compared with that of a control. The test measures the effect of freezing and thawing upon the physical integrity of the sample. This test has been standardized as ASTM D 4842.

For each of the samples tested, a single dynamic leaching test was performed, at least 2 hydraulic conductivity measurements were performed, and unconfined compressive strength and freeze–thaw weathering resistance were measured in triplicate. Unconfined compressive strength of all 14 samples collected at the time of field solidification was also measured after 56 days and after 19 months of curing, but strength after immersion was measured for only 7 of the samples cured for 56 days in order to conserve samples for later testing.

Aside from unconfined compressive strength, the different ages of the laboratory and field prepared specimens, which were tested at 56 days and 7 months, respectively, were not expected to result in significant differences.

2.3. Chemical analysis

Total digestion of solid samples was performed using repeated treatments of nitric acid, followed by hydrofluoric acid and aqua regia, and then hydrogen peroxide. Liquid extracts for boron, cadmium, chromium, copper, lead and zinc were preserved to pH 2 with nitric acid and analyzed using sequential inductively coupled plasma spectrophotometry. Extracts for mercury were preserved with potassium dichromate and sulfuric acid to pH 2, and analyzed by cold vapor atomic adsorption spectrometry.

2.4. Statistical analysis

For each test of the WTC solidified waste evaluation protocol, the results obtained from the number of replicates specified for that test were used to calculate average results for each archived sample. These average values were then used to calculate an overall average and standard deviation for all the archived samples tested (i.e., usually 10).

In comparing the results for the field samples with those for the design formulation, a difference of less than 1 standard deviation from the mean was considered to be insignificant; a difference of 1 to 2 standard deviation from the mean was considered possibly significant, and a difference of 2 standard deviations or more from the mean was considered to be significant. This categorization may be thought an oversimplification of statistical significance testing by some, but is sufficient to classify conspicuous differences between laboratory and field samples for the purposes of this article.

3. Results and discussion

3.1. Field solidification

Tables 3 and 4 show a summary of the data recorded for the preparation of solidified waste batches in the field, and the specifications based on the design mix developed in the laboratory, respectively. Comparison of the total component masses shows that the waste and binder dosages were increased by only 2.8% and 4.9%, respectively. However, the water consumption by the field mix was 19% higher than had been anticipated in the laboratory, which also resulted in a 22% higher overall sodium silicate addition¹.

Expressed as a fraction of the mix, Tables 3 and 4 show that the overall proportions of dry components in the 63 m³ of solidified waste deviated from the design by less than 2%. The standard deviation indicates that the variation between batches was small, but the ranges show that there were occasional wide deviations from the design. These were caused primarily by unavoidable field equipment malfunctions such as sticking valves, clumping of mixing components in the storage and conveyance systems, and at times, instability of weigh-scale readings in high winds. Whenever a malfunction occurred which could have been detrimental to the mix, waste processing was discontinued until the problem had been corrected. In general, the water consumption of the EAF dust was highly variable, and required continual adjustment (based on visual observations at the mixer discharge to the pump) to yield a pumpable mix with minimum water content. The load cells were accurate to within 1 kg, so the error in weighing was negligible in comparison to the recorded variations.

3.2. Testing of solidified waste

The results from testing of the field archived samples according to Levels 0, 1 and 2 of the WTC solidified waste evaluation protocol are presented and compared with the results from the design formulation prepared in the laboratory in Table 5, Table 6, and

Table 3
Summary of field solidification data (based on mixing records for a total of 414 batches)

Mix component		Waste	Dry binder	Silicate	Water
Total mass (tonne)		63	41	2.8	33
% of dry mix	Average	58.9	38.5	2.6	31.1
	Range ^a	53–62	36–44	0.5–3.1	14–38
	Standard deviation ^a	0.8	0.8	0.5	2

^a Batch-to-batch variation.

¹ % increase or decrease was calculated as $100 \times (\text{actual mass} - \text{design mass}) / \text{design mass}$.

Table 4
Design specifications based on laboratory formulation development

Component	Waste	Dry binder	Silicate	Water
Total mass (tonne)	61.3	43.1	2.3	27.8
% of dry mix	57.4	40.4	2.1	26

Table 5
Results of level 0 testing of basic properties of solidified waste

Parameter	Design formulation	Field average	Standard deviation
Bulk density (kg m^{-3})	2340	2220	80
Moisture content (%)	15.3	16.8	1.4
Solids specific gravity	2.22	2.39	0.10
<i>Bulk contaminant concentration (mg kg^{-1} of dry solidified waste)</i>			
Boron	^a	211	25
Cadmium	^a	74	8.9
Chromium	^a	22200	5670
Copper	^a	4260	537
Lead	^a	5330	1320
Mercury	^a	5.66	0.42
Zinc	^a	25700	3220

^a Not measured.

Table 6
Results from level 1 evaluation of chemical immobilization of contaminants

Parameter	Design formulation	Field average	Standard deviation
<i>Initial leachate concentration (mg l^{-1})</i>			
Boron	2.56	2.49	0.84
Cadmium	0.01	< 0.01	NA
Chromium	0.43	0.56	0.41
Copper	0.14	0.22	0.02
Lead	0.21	1.80	0.35
Mercury	< 0.00003	0.00081	0.00021
Zinc	0.37	1.07	0.45
Final pH of leachate	12.4	12.8	0.07
<i>Amount available for leaching (mg kg^{-1} of wet solidified waste)</i>			
Boron	59.0	60.2	12.0
Cadmium	26.4	34.1	5.1
Chromium	30.4	268	227
Copper	30.0	500	259
Lead	5.86	530	184
Mercury	0.01	0.040	0.034
Zinc	4040	12900	2360
Final pH of leachate	6.8	6.2	0.4

Table 7
Results from level 2 evaluation of physical encapsulation of contaminants

Parameter	Design formulation	Field average	Standard deviation	
<i>Contaminant mobility in the matrix (l)</i>				
Boron	> 11 ^a	> 10.0	NA	
Cadmium		> 10.7	NA	
Chromium		> 15.0	NA	
Copper		> 11.6	NA	
Lead		> 12.2	NA	
Mercury		> 11.4	NA	
Zinc		14.2	0.4	
Hydraulic conductivity (m/s at 20°C)	< 10 ^{-10a}	1.70 × 10 ⁻¹⁰	1.84 × 10 ⁻¹⁰	
<i>Unconfined compressive strength (MPa)</i>				
56 day	Before immersion	23.5	8.97	6.40
	After immersion		7.60	5.56
7 month	Before immersion	Not measured	20.1	3.16
	After immersion	Not measured	18.9	4.44
19 month	Before immersion	Not measured	16.0	2.79
	After immersion	Not measured	14.1	4.15
Freeze/thaw (% mass loss)	0.02	-0.04	0.83	

^a Results are for a design mix with a higher EAF dust content (i.e., 65.7% instead of 57.4%).

Table 7, respectively. Plots of pH as a function of acid addition, for evaluation of acid neutralization capacity, are shown in Fig. 1.

The data summarized in Table 5 indicate that the results from Level 0 testing of the design formulation differed from those of the field solidified waste by less than 2 standard deviations, i.e., the differences were only possibly significant. Nevertheless, true differences in bulk density and moisture content may exist because of the higher water addition in the field as compared with the design formulation. A higher proportion of water would be expected to lower the bulk density, and increase the measured moisture content, as was observed.

Contaminant concentrations in the solidified wastes are in the expected range, in light of dilution of the contaminant concentrations measured for the raw waste (Table 1).

The results from the equilibrium extraction, presented as initial leachate concentrations in Table 6, are strikingly similar in the field and design formulations. The notable exceptions are lead and zinc, which are significantly higher in the field samples, at 1.80 and 1.07 mg l⁻¹, respectively, than in the design formulation, at 0.21 and 0.37 mg l⁻¹, respectively. This effect is attributable to the higher average pH of the field samples, at 12.8, than the design formulation, at 12.4. In this pH range, a small difference in pH causes a large change in solubility of amphoteric metals. The pH of the field samples was higher for several reasons: (1) high calcium lime was used in the field solidification, whereas dolomitic lime was used in the design formulation, (2) the dosage of sodium

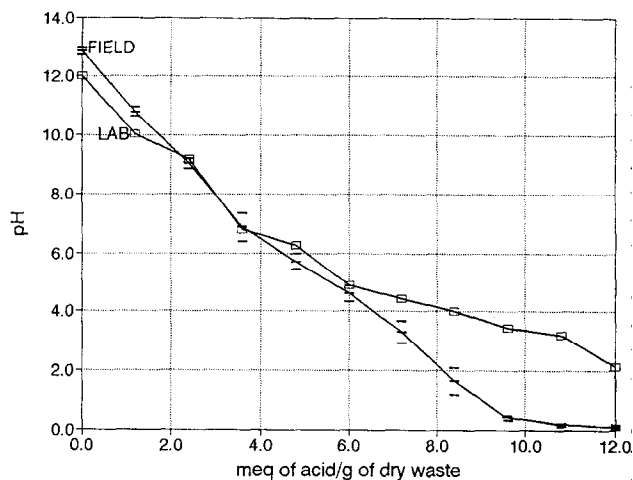


Fig. 1. pH as a function of acid addition. The 'field' plot shows the average \pm standard deviation for ten samples.

silicate activator was higher in the field than in the laboratory, and (3) hydration reactions, which can be expected to consume alkalinity, were slower during initial curing of field samples at the cooler field temperature, than they were in the laboratory. These results illustrate the importance of maintaining a pH regime in which contaminants have their lowest solubility. It may be advisable to include pH, or even acid neutralization capacity measurement, as a field quality assurance/quality control parameter.

With the exception of boron and cadmium, the contaminant amounts available for leaching from the field samples were much higher than from the design formulation. Again, the final extract pH was likely the controlling factor, as it was 6.8 for the design formulation, and only 6.2 for the field samples. In this pH range, the observed pH difference of 0.6 can cause several orders of magnitude difference in metal solubility. Boron was not affected because its solubility is pH independent below pH 8 [7]. Extraction of leachable cadmium was likely complete at both pH values. The cause of the pH difference between the design and field samples is unknown. It is noteworthy that the sodium acetate buffer solution did not succeed in maintaining the leachate pH at 5, as was intended.

The average pH's of the field samples, with error bars indicating the standard deviation, have been plotted as a function of acid addition in Fig. 1. The acid neutralization capacity of the design formulation, also tested after 7 months of curing, has been plotted for comparison. These plots confirm the higher initial pH of the field samples which was found in the equilibrium extraction experiments. The field samples and the design formulation were all capable of neutralizing 2.4 meq of nitric acid per g of dry waste, before reaching pH 9. A disparity in pH response at acid additions greater than 6 meq g^{-1} can be ascribed to a characteristic variation in the composition of the EAF dust, and does not have a practical significance, as the solidified waste matrix will be substantially decomposed in this pH range (at a pH less than 4) in any case.

With the exception of zinc, the contaminant concentrations leached in most intervals of the ANSI/ANS 16.1 dynamic leaching test were uniformly lower than the detection limit, indicating low mobility of the contaminants in the matrix. Based on the detection limit, the leachability indices are reported as 'greater than' values in Table 7, without a standard deviation. The standard deviation for zinc, however, represents less than 3% of the mean for the 10 samples (14.2), indicating that this parameter was not highly variable.

At $1.70 \times 10^{-10} \text{ m s}^{-1}$, the hydraulic conductivity of the field samples appeared to be slightly higher than that of the design formulation, which was too low to be quantified. A higher water addition in the field, which was also evident in the bulk density measurements, may have adversely affected the hydraulic conductivity. The hydraulic conductivity of the specimens molded in the field was still low enough that mobility of contaminants by diffusion should be greater than by advection. However, the degree of compaction of the actual waste material placed in the experimental field test cell may be less than that of the archived samples, potentially resulting in a yet higher field hydraulic conductivity. The standard deviation for this parameter represented 109% of the mean; such high variability is typical of this measurement, and is not necessarily indicative of nonuniformity in the solidified product [8].

Inspection of the 56-day unconfined compressive strengths in Table 6 reveals that the average strength of the field samples was significantly lower than that of the design formulation. 56-day strengths before immersion have been plotted as a function of moisture content in Fig. 2 to demonstrate that there is an inverse relationship between strength and moisture content. It appears that the low average and high standard deviation calculated for the 56 day unconfined compressive strength can be attributed in large part to the variability in the moisture content of the solidified samples. High strength is not per se important for solidified products, which require little strength (350 kPa is often recommended) to withstand handling and traffic. However, strength is

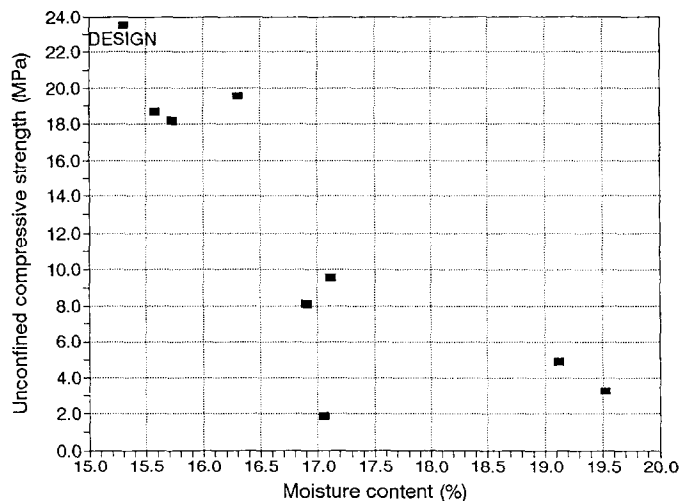


Fig. 2. 56 day unconfined compressive strength as a function of moisture content.

indicative of the progress of hydration reactions which are crucial to development of a dense, durable structure to physically entrap contaminants. Thus, it seems advisable to limit the water content of solidified products to the extent possible, as is common practice for cement and concrete.

After 7 months of curing the field samples became more than twice as strong, on average, as they had been at 56 days, but their strength before immersion decreased by 20% between 7 and 19 months of curing. In addition, the relationship of strength with moisture content was not as evident for the older samples as some of the denser samples became brittle with increasing age, resulting in lower than expected unconfined compressive strengths. This effect was particularly noticeable for strengths after immersion; additional densification in the presence of water resulted in swelling and cracking in some instances. Overall, however, there was less variation in the strengths of the older samples.

The freeze–thaw resistance of both the design and field specimens was excellent, with negligible weight loss after 12 cycles of freeze–thaw.

4. Conclusions

As could be expected, it was found that both the chemical and physical properties of waste solidified in the field differed from those of waste solidified in the laboratory, due primarily to the exigencies and vagaries of field processing. Within the different field samples, the chemical and leaching properties were generally consistent from sample to sample, whereas the physical properties were more variable. Overall, however, the quality of the field solidified samples was still satisfactory, and the field solidified products met the performance criteria for physical encapsulation of contaminants (i.e., Level 2) recommended by the WTC solidified waste evaluation protocol, as had the design formulation. It should be noted that a great effort was made in this study to produce a homogeneous solidified product using readily available and yet effective dosing and mixing equipment. An equally satisfactory correspondence between field and laboratory data can only be expected when equivalent care is taken in field processing.

Some of the specific findings regarding the field and laboratory samples are summarized in the following points.

4.1. Field solidification

The dry additive blend differed from the design blend by less than 1%.

Unavoidable disturbances during processing resulted in wide deviations from the design mix for occasional batches, but the overall proportions of dry components in the field solidified waste differed from the design mix by less than 2%. This difference was of greater importance for components which were present in the mix in small dosages, e.g., an increase in the overall sodium silicate dosage of 0.5% of the mix represented a 22% increase in the amount of sodium silicate added.

The water consumption of the field mix was variable and higher overall than had been anticipated during formulation development in the laboratory.

4.2. *Physical characteristics of solidified waste*

Variable and higher than planned water addition during field solidification resulted in a lower average bulk density, a more variable and higher moisture content, a higher hydraulic conductivity, and a more variable and lower unconfined compressive strength in the field samples as compared with the design formulation.

In spite of the observed differences and variabilities, the hydraulic conductivity remained below the most stringent performance criterion of 10^{-9} m s⁻¹, the unconfined compressive strength was much higher than the most stringent performance criterion of 350 Kpa recommended by the WTC solidified waste evaluation protocol, and weight loss in the freeze–thaw test was minimal.

4.3. *Chemical and leaching characteristics of solidified waste*

Higher than planned sodium silicate addition, and use of high calcium lime rather than dolomitic lime resulted in a higher initial pH, and higher initial (i.e., distilled water) leachability of lead and zinc in the field samples than in the design formulation.

The contaminant amounts available for leaching from the design and field samples varied considerably because the final extract pH values were different. The sodium acetate buffer solution did not control the leachate pH values at 5, as was intended.

The leaching characteristics of the field samples were remarkably consistent among the different batches, and did not appear to be sensitive to the variations in solidified product composition.

The leachability indices determined in the ANS/ANSI-16.1 test for all contaminants in both the design and field batches were better than the most stringent performance criterion of 9 recommended by the WTC solidified waste evaluation protocol.

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