Technical Report EL-93-10
April 1993

(2)

US Army Corps of Engineers
Waterways Experiment Station

An Evaluation of Stabilization/Solidification of an Inorganic Wood-Preserving Waste

by *Michael G. Channell, Teresa T. Kosson*
Environmental Laboratory

Prepared for U.S. Environmental Protection Agency

Technical Report EL-93-10
April 1993

An Evaluation of Stabilization/Solidification of an Inorganic Wood-Preserving Waste

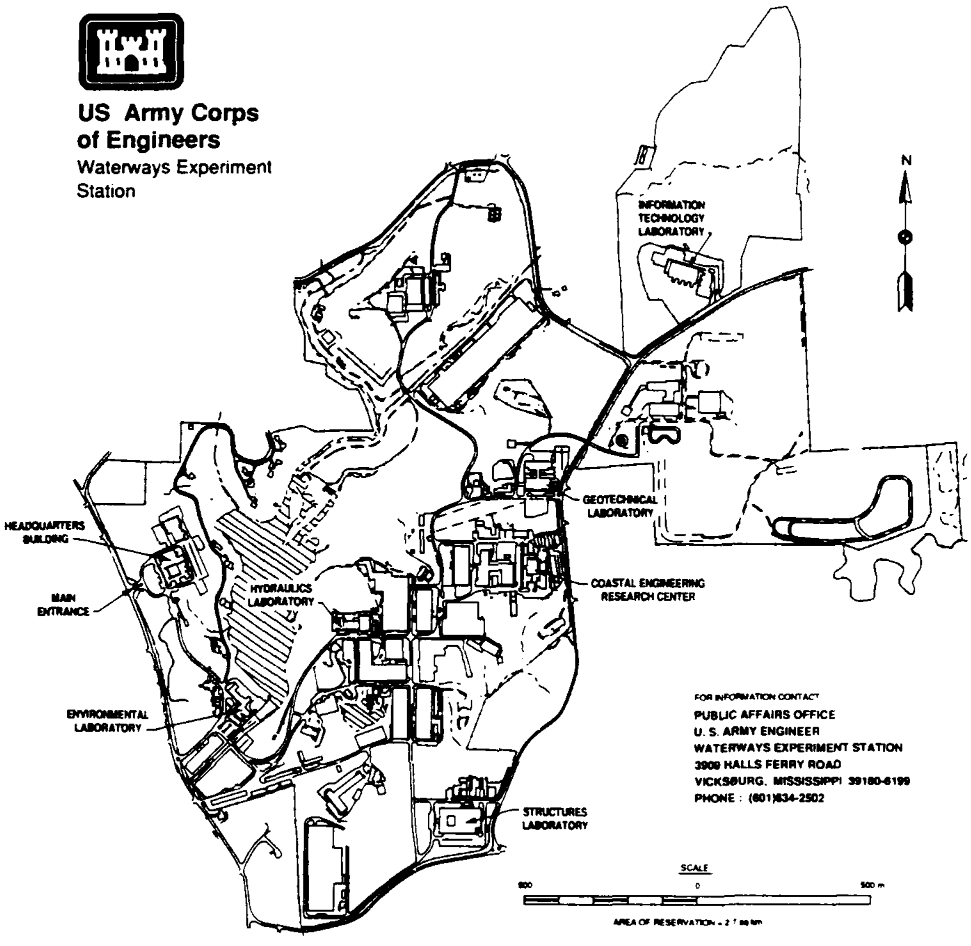
by Michael G. Channell, Teresa T. Kosson
Environmental Laboratory

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final Report

Prepared for Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Technical Evaluation and Development Section
Cincinnati, OH 45268

US Army Corps of Engineers
Waterways Experiment Station



Waterways Experiment Station Cataloging-in-Publication Data

Channell, Michael G.
An evaluation of stabilization/solidification of an inorganic wood-preserving waste / by Michael G. Channell, Teresa T. Kosson ; prepared for U.S. Army Corps of Engineers.
42 p. : ill. ; 28 cm. — (Technical report ; EL-93-10)
Includes bibliographical references.
1. Wood — Preservation — Waste disposal. 2. Arsenic wastes. 3. Binders (Materials) 4. Factory and trade waste — Leaching. I. Kosson, Teresa T. II. Risk Reduction Engineering Laboratory (U.S.) III. United States. Environmental Protection Agency. III. U.S. Army Engineer Waterways Experiment Station. IV. Title. V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL-93-10.
TA7 W34 no.EL-93-10

Contents

List of Figures

Preface

This report was prepared for the U.S. Environmental Protection Agency (USEPA), Risk Reduction Engineering Laboratory, by the U.S. Army Engineer Waterways Experiment Station (WES).

The work was performed during the period July to September 1992 by Ms. Teresa Kosson and Mr. Michael Channell, Environmental Restoration Branch (ERB), Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Chemical analyses were performed by the Environmental Chemistry Branch, WES. The work was conducted at WES under the direct supervision of Mr. Norman R. Francingues, Chief, ERB, and the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Director, EL. Project officer for the USEPA was Mr. Ron Turner.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

This report should be cited as follows:

> Channell, M. G., and Kosson, T. T. (1993). "An Evaluation of stabilization/solidification of an inorganic wood-preserving waste," Technical Report EL-93-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (U.S. liquid)	3.785412	liters
inches	0.0254	meters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimeters

1 Introduction

Background

Amendments to the Resource Conservation and Recovery Act (RCRA), enacted through the Hazardous and Solid Waste Amendments of 1984, impose substantial responsibilities on handlers of hazardous waste. In particular, these amendments prohibit the continued land disposal of untreated hazardous wastes beyond specified dates "unless the Administrator determines that the prohibition...is not required in order to protect human health and the environment for as long as the wastes remain hazardous..." (RCRA Sections 3004(d)(1), (e)(5), 42 USC 6924(D)(1), (e)(1), and (g)(5)).

Wastes treated according to treatment standards set by the U.S. Environmental Protection Agency (USEPA) under Section 3004(m) of RCRA are not subject to the prohibitions and may be land disposed. The statute requires USEPA to set "levels or methods of treatment, if any, that substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized..." (RCRA Section 3004(m)(1), and 42 USC 6924 (m)91).

To expedite the development of treatment standards, various deadlines were established for agency action. Further land disposal of a particular group of hazardous wastes is prohibited at certain deadlines if the USEPA has not set treatment standards under RCRA Section 3004(m) for such wastes or determined, based on a case-specified petition, that there will be no migration of hazardous constituents from the units for as long as the wastes remain hazardous. Additional deadlines result in conditional restrictions on land disposal to take effect if treatment standards have not been promulgated or if a petition has not been granted.

Treatment standards will be established based on Best Demonstrated Available Technology (BDAT) and developed according to RCRA Section 3004(m). USEPA (1986a) defines a technology as best, demonstrated, and available as follows:

a. Best--if several technologies are available for treating the same (or similar) waste(s), the waste-treatment method that reduce the concentration and/or the migration of contaminants most effectively is considered best.

b. Demonstrated--for a waste-treatment technology to be considered demonstrated, a full-scale facility must be known to be in operation for treating the waste.

c. Available--for a waste-treatment technology to be considered available, it must (a) not present a greater total risk than land disposal, (b) be able to be purchased or licensed from the proprietor if a technology is a proprietary or patented process, and (c) provide substantial treatment.

Stabilization/solidification (S/S) is one technology that meets the demonstrated and available criteria (USEPA 1986c). S/S of hazardous wastes has been proposed as a treatment method for substantially reducing the likelihood of contaminant migration. USEPA has initiated studies to evaluate S/S technology as a BDAT and to develop data to support the establishment of treatment standards.

Stabilization/Solidification

S/S is a process that involves the mixing of a hazardous waste with a binder material to enhance the physical and chemical properties of the waste and to chemically bind any free liquid (USEPA 1986c). Typically, the binder is a cement, pozzolan, or thermoplastic. Proprietary products may also be added. Often, the S/S process is changed to accommodate specific wastes. Since completely discussing all possible modifications to an S/S process is not possible, discussions of most S/S processes have to be related directly to generic process types. The performance observed for a specific S/S system may vary widely from its generic type, but the general characteristics of a process and its products are usually similar. Comprehensive general discussions of waste S/S processes are given in Malone and Jones (1979); Malone, Jones, and Larson (1980); Iadevaia and Kitchens (1980); and USEPA (1986b).

Waste S/S systems that have potential BDAT applications include the following:

a. Lime/fly ash pozzolanic processes.

b. Pozzolan-portland cement systems.

c. Vitrification.

Lime/fly ash pozzolanic processes use a finely divided, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. The waste containment is produced by entrapping the waste in the pozzolan concrete matrix (microencapsulation). Metals are also usually converted to less soluble forms that further inhibit leaching.

Pozzolan-portland systems use portland cement and fly ash or other pozzolan materials to produce a type of waste/concrete composite. Contaminant migration is reduced by microencapsulation of the contaminants in the concrete matrix. The addition of soluble silicates to pozzolan-portland systems may accelerate hardening. As with lime/fly ash pozzolonic systems, metals are also converted to less soluble forms in the pozzolan-portland systems.

Vitrification is a process whereby hazardous wastes are converted into a glassy substance utilizing very high temperatures. The process is carried out by inserting electrodes into a waste mass and passing a high current of electricity through the mass. The high temperature produces a melt; and as the melt cools, contaminants are trapped in the melt. The melt when cooled forms a stable noncrystalline solid that resembles obsidian, a very strong glass.

Waste of Interest

The soils evaluated for S/S as a treatment method were contaminated with inorganic wood preservatives consisting mainly of arsenic and chromium. The soil was obtained from Emille, AL, by Mr. Ron Turner, USEPA Risk Reduction Engineering Laboratory (RREL), and Mr. Dan Patel, Science Applications International Corporation (SAIC), Rockville, MD. The soil was packed in four 5-gal[1] buckets and transported to the U.S. Army Engineer Waterways Experiment Station (WES) by Mr. Turner and Mr. Patel. Upon receipt at WES, the soils were visually inspected and had a yellow liquid on the surface. The waste was received under chain of custody and placed in a walk-in cooler at 4 °C for storage until needed for testing.

Purpose and Scope

The specific objectives of the study were to determine if S/S techniques could be applied to a soil contaminated with wood-preserving waste and to characterize the effect of S/S on that soil. The physical and chemical properties of the stabilized/solidified wood-preserving waste were evaluated to determine if S/S techniques could substantially reduce the amount of hazardous contaminants in the Toxicity Characteristic Leaching Procedure (TCLP) leachate and improve the physical-handling properties of the soils.

---

[1] A table of factors for converting non SI units of measurement to SI units is presented on page vi.

Three binders (cement, kiln dust, and lime/fly ash) were used to stabilize/solidify the waste. The stabilized/solidified waste was cured, and the physical and chemical properties of the treated samples were evaluated. The unconfined compressive strength (UCS) test was used to measure physical strength, and the TCLP was used to assess the leachability of the chemical contaminants from the stabilized/solidified waste.

This report presents the methods and test results from the S/S of the waste material. It is not intended to determine, nor does it attempt to determine, whether S/S is a BDAT for the treatment of the inorganic wood-preserving waste.

Organization of Report

This report is divided into four basic parts:

a. Chapter 1 briefly describes the background for this study and introduces the concept of S/S.

b. Chapter 2 describes the methods used for sampling, treatment, and testing of the waste materials.

c. Chapter 3 describes the results of UCS and TCLP of the stabilized/solidified wood-preserving waste.

d. Chapter 4 presents conclusions based on the results of testing.

2 Materials and Methods

General Study Approach

This investigation was conducted in the following four phases:

a. *Phase I: Sample Collection*. Soils were collected in four 5-gal buckets and transported to WES under chain of custody Mr. Ron Turner and Mr. Dan Patel.

b. *Phase II: Preparation of Test Specimens*. Test specimens of S/S waste were prepared. Preparation of the test specimens included an initial screening test to determine the appropriate water/binder/waste ratios for detailed evaluation.

c. *Phase III: UCS and TCLP Testing*. Strength characteristics were evaluated using the UCS test. The leachability or leaching potential of arsenic and chromium were evaluated using the TCLP.

d. *Phase IV: Data Compilation*. Data from WES and USEPA contractors were compiled; the study results are discussed in this report.

Sample Collection

After the soils were collected and transported to WES, samples of the raw waste were analyzed for total composition by SAIC, the contractor for RREL.

On 15 August 1991, the WES Hazardous Waste Research Center (HWRC) received four 5-gal plastic buckets of soil samples under chain of custody.

To assess the variability of the sampling and treatment processes, the soil was homogenized and divided into four subsamples and treated separately. Each subsample was prepared by first homogenizing each bucket, then randomly combining one-fourth of the contents of each bucket in a 60-ℓ stainless steel bowl and mixing the waste with a Hobart mixer. The four subsamples were then placed in the original containers, labeled subsample A, B, C, and D, and stored in a cooler at 4 °C until needed for testing.

Preparation of Test Specimens

General description of S/S evaluation process

Three S/S processes were used to stabilize/solidify the wood-preserving waste and were differentiated by the type of binder material used in the process. The binders evaluated were portland cement, kiln dust, and lime/fly ash. Compositional and chemical analyses of binders used in this study are presented in Tables 1 and 2.

The S/S process involves the addition of water and binder material to the waste followed by mixing and curing. A schematic flowchart of the S/S processing is shown as Figure 1.

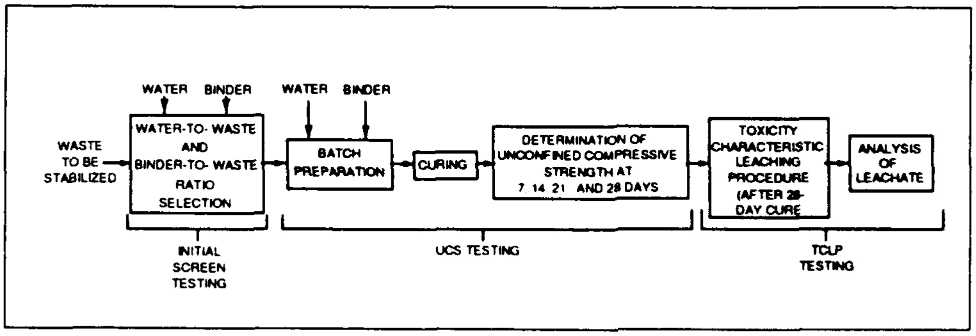


Figure 1. Schematic flowchart for stabilization processing

Initial screening test

The purpose of the initial screening test was two-fold: first, to determine the appropriate water-to-waste ratio (WWR) necessary for hydration; and second, to narrow the range of binder-to-waste ratios (BWR) used for detailed evaluation. Because the soil had a high moisture content, water was not always necessary for hydration. The matrix of test specimens prepared during the initial screening test is shown in Table 3. The initial BWR screening test involved mixing binder, water, and soil in a Hobart K455S mixer at three WWR weight ratios, 0.0, 0.05, and 0.10 based on the wet weight of the soil. These ratios were chosen on the basis of previous experience of the testing personnel and the appearance of the soils as they were prepared.

Determination of the optimal BWR and WWR was based on the results of the Cone Index Test (CI) performed on the initial screening test samples after they had cured at 23 °C and 98-percent relative humidity for 48 hr. The CI measures the resistance of a material to the penetration of a 30-deg right circular cone. The method specified in TM 5-530 was followed (Headquarters, Department of the Army 1971). The CI value is reported as force per unit surface area (pounds per square inch) of the cone base required to push the cone through a test material at a rate of 72 in./min. Two cones are available for this test. The standard WES cone has an area of 0.5 sq in., and the airfield penetrometer has a base area of 0.2 sq in. It was convenient to use the standard WES cone on material with a CI less than 100 psi and to use the airfield penetrometer on materials with a CI greater than 100 psi. The maximum CI value that can be measured by the airfield penetrometer is 750 psi; therefore, materials having CI values greater than 750 psi are reported simply as >750 psi.

The results of the initial screening test define the optimal WWRs and produce data that aid in the selection of the BWRs for preparation in the detailed evaluation. The test specimens prepared during the initial screening test were not evaluated further.

Preparation of specimens for detailed evaluation

Subsamples A, B, and C were stabilized/solidified using cement, kiln dust, and lime/fly ash. Three BWRs were evaluated for the cement and kiln dust binders, and four BWRs were evaluated for the lime/fly ash.

Table 4 summarizes the matrix of test specimens prepared for the detailed evaluation. Water was not added for the nine batches of stabilized/solidified waste that were prepared for the cement and kiln dust processes. For the lime/fly ash stabilization/solidification processes, each of the four BWRs was prepared in triplicate for a total of 12 batches using a 0.05 WWR. These batches were differentiated by the alphanumeric codes shown in Table 4.

Treated specimens were prepared by mixing the soil, binder, and water (if added) in a Hobart K455S mixer. The binder/water/waste mixture was poured into 2- by 2-in. brass molds. To aid in removing UCS test specimens, a light coating of Lubriplate grease was applied to the molds. Specimens used for the TCLP test were prepared in ungreased molds. Immediately after the waste mixtures were placed in the molds, they were vibrated on a Sentron model VP61D1 vibration table to remove air voids. At the high binder ratio, some of the binder/water/waste mixtures were very viscous; and vibration was an ineffective method for removing air voids. These specimens were compacted in the 2- by 2-in. molds using a compaction hammer with a 5.74-lb weight, a 1.8- by 1.0-in. brass head and a 12-in. drop. Compaction was accomplished by placing two layers of the binder/water/waste mixture in the molds and dropping the weight five times per layer.

The molded S/S specimens were cured in the molds at 23 °C and 98-percent relative humidity for a minimum of 24 hr. During this time, the specimens were observed to determine if any free liquid formed on the surface. Specimens were removed from the molds when they developed sufficient strength to be free-standing and were cured under the same temperature and relative humidity conditions until further testing.

UCS and TCLP Testing

Unconfined compressive strength

UCS was used to define and characterize the effects of the S/S process on the physical strength of the S/S waste mixture. The UCS of the treated waste was determined using the American Society for Testing and Materials (ASTM) method C 109-86 (ASTM 1986). The only deviation from this method was vibration or compaction of the specimens as discussed previously.

UCS testing was performed on cubes after they had cured for 7, 14, 21, and 28 days. One cube for each batch of binder/waste mixture was tested at each curing time. The dimensions of each specimen was measured with a Fowler Max-cal caliper. The surface area was then calculated by multiplying the two measurements to obtain the area in square inches. Each cube was crushed with a Tinius Olsen Super-L compression apparatus. UCS was reported as the pounds per square inch required to fracture the cube.

Toxicity characteristic leaching procedure

Selection of binder ratio for leaching characteristics. For the purpose of this study, the UCS test was selected to determine the binder ratio for evaluation of leaching characteristics. One cube from each treatment batch was subjected to the UCS test at the completion of the 28-day cure period, as previously discussed. The stabilized BWR that produced a UCS value closest to but greater than 50 psi was the binder ratio used to assess the effects of S/S on the contaminant-release properties of the treated soil. A UCS of 50 psi was chosen based on information found in the Office of Solid Waste and Emergency Response Policy Directive 9487.00-2A (USEPA 1986e); and based on this criteria, one binder-to-waste ratio was selected for each S/S process for TCLP extraction and analysis. A TCLP extraction was performed in triplicate for each BWR selected for detailed evaluation. A total of nine TCLP extractions representing triplicates of each binder:waste:water ratio for each binder were performed.

Toxicity characteristic leaching procedure. The TCLP was selected by USEPA as the test protocol for evaluating chemical mobility. The TCLP was conducted using the procedure established by USEPA (USEPA 1986d). TCLP extracts were collected according to the methods described in USEPA (USEPA

1986f). The TCLP extracts were forwarded under chain of custody to the WES Environmental Chemistry Branch (ECB) for chemical analysis.

Analytical procedures. TCLP extracts were analyzed for metals according to the methods and within the time constraints summarized in the *Federal Register* (USEPA 1986d) and specified in SW-846.

Quality assurance/quality control. The quality assurance/quality control (QA/QC) for this project was divided by the WES HWRC and WES ECB. The WES HWRC was responsible for the TCLP extraction preparation and for preparation of the method blanks for each S/S waste mixture extracted. The WES ECB performed the chemical analysis of the TCLP extracts. Duplicates were run on the samples as required.

3 Discussion of Results

Initial Screening Test Results

Cement binder

The initial screening test results for the cement binder are presented in Table 5. The initial screening results indicate that all specimens developed a CI value greater than 750 psi after curing 48 hr. The results also show that the specimens prepared without the addition of water developed strengths similar to those to which water was added. Batch formulations of 0.10, 0.15, and 0.20 BWRs without the addition of water were selected for detailed testing and evaluation.

Kiln dust binder

Results of the initial screening test for the kiln dust binder are presented in Table 6. The results show that as water was added to the sample, the lower BWR specimens developed less strength. This is probably because there was an excess of water in the specimen after the hydration of the binder had occurred. In the evaluation with no water addition, the 0.2 BWR sample developed twice as much strength as did the 0.1 BWR sample. Thus, batch formulations of 0.1, 0.2, and 0.3 BWRs and no water addition were selected for leaching characteristics.

Lime/fly ash binder

Initial screening test results for the lime/fly ash binder are presented in Table 7. The data indicate that the samples prepared using 0.05 WWR developed the most strength. The WWRs of 0.0 and 0.10 only developed strengths around 180 psi, while the 0.05 WWR samples ranged from 161 to 700 psi. At the ratios of 0.1 lime/0.1 fly ash and 0.05 water, the CI was 161 psi. By increasing the fly ash ratio to 0.3, the CI was increased to 600 psi. At the sample ratio of 0.2 lime/0.1 fly ash and 0.05 water, the CI was 400 psi. By increasing the fly ash ratio to 0.2, the CI was increased to 700 psi. Based on these data, batch formulations of 0.1 lime/0.1 fly ash, 0.1 lime/0.2 fly ash, 0.2 lime/0.1 fly ash, and 0.2 lime/0.2 fly ash with a water ratio of 0.05 were selected for further detailed testing and evaluation.

UCS Results

The results of the UCS tests are presented as tables in Appendix A and discussed below.

Cement binder

Figure 2 presents a graph of the average UCS versus curing time for the treated soil when cement was used as the binder. Based upon the 28-day UCS, the UCS increases as the BWR increases. The results were 460 psi, 605 psi, and 874 psi for the BWRs of 0.1, 0.15, and 0.2, respectively. The 0.15 BWR gained strength as curing time increased throughout the test. An anomaly in the results occurred in the 14-day tests for the 0.1 and 0.2 BWRs. The UCS dropped significantly for the 0.2 BWR and increased significantly for the 0.1 BWR. This could be due to a number of reasons that are beyond the scope of this report. With the exception of these two points, the results increased as curing time increased.

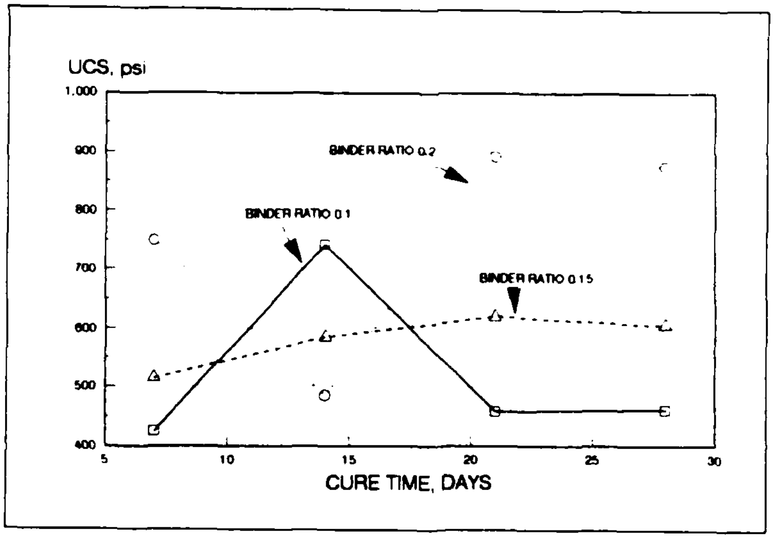


Figure 2 UCS versus curing time for the S/S wood-preserving waste using different cement binder ratios

Kiln dust binder

As indicated in Figure 3, results similar to the cement UCS data were observed when kiln dust was used as a binder. The UCS for the kiln dust samples increased as the BWR was increased; however, the waste treated with kiln dust developed a lower UCS than the cement-treated waste samples. The results show that strengths increase as the cure time increases. The 0.3 BWR appeared to gain the most strength at 21 days of cure, while the 0.2 and 0.1 BWRs appeared to obtain a maximum strength at 28 days of curing time.

Lime/fly ash binder

The interpretation of the lime/fly ash UCS data is more difficult than the cement and kiln dust UCS data because both the lime BWR and the fly ash BWR were varied. Figure 4 is a plot of the UCS versus cure time for each of the lime/fly ash binder ratios. The 0.2/0.1 and 0.2/0.2 lime/fly ash ratios developed the most strength at 28 days of cure. The 0.1/0.2 lime/fly ash ratio gained maximum strength at 21 days of cure, but still had a UCS similar to the 0.2/0.1 and 0.2/0.2 lime/fly ash ratios. The 0.1/0.1 lime/fly ash ratio did not develop enough strength to meet the 50-psi criteria. The graph shows that the specimen obtained a UCS of 44 psi at 28 days of cure.

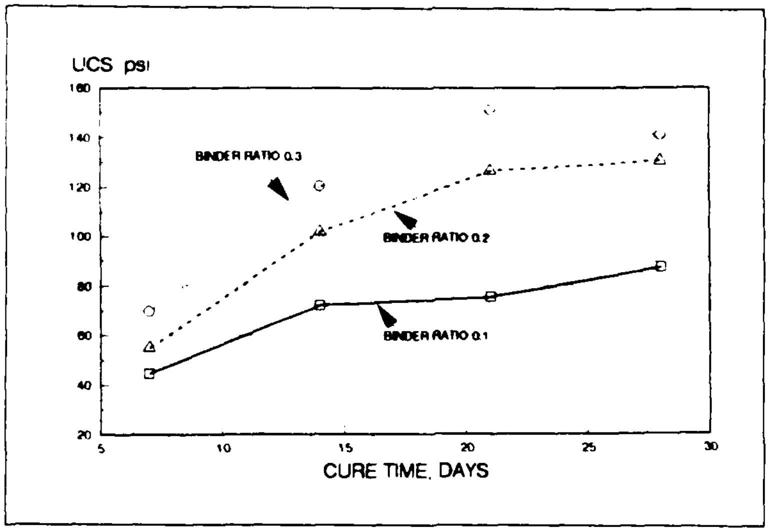


Figure 3 UCS versus curing time for the S/S wood-preserving waste using different kiln dust binder ratios

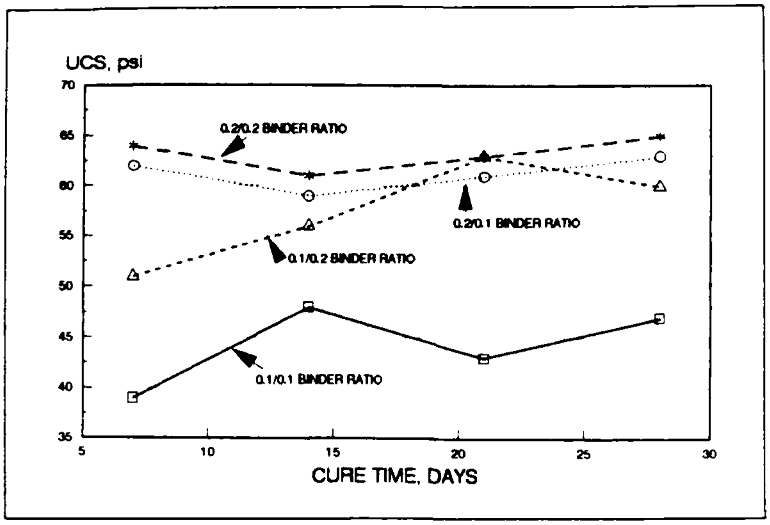


Figure 4. UCS versus curing time for the S/S wood-preserving waste using different lime/fly ash binder ratios

Figure 5 compares the 28-day UCS values obtained for each of the binder materials evaluated. The specimen treated with cement developed a greater UCS than the kiln dust and lime/fly ash treated specimens. The lime/fly ash treated specimens had the lowest UCS.

Bleed Water Results

The samples were prepared and placed in an environmental chamber at 23 °C and 98-percent relative humidity for a minimum of 24 hr. Visual observations were conducted to determine if any of the samples leached free liquid on the surface. No samples indicated the formation of free liquid on specimens.

Ratios Selected for TCLP Extraction

With the exception of one lime/fly ash BWR, the BWRs investigated developed UCS above the 50-psi UCS selection criterion (See Figure 5). The materials designated for TCLP analysis were chosen by selecting the batch with the minimum BWR that obtained a UCS of 50 psi or greater. The specimens selected for TCLP extraction are listed in Table 8.

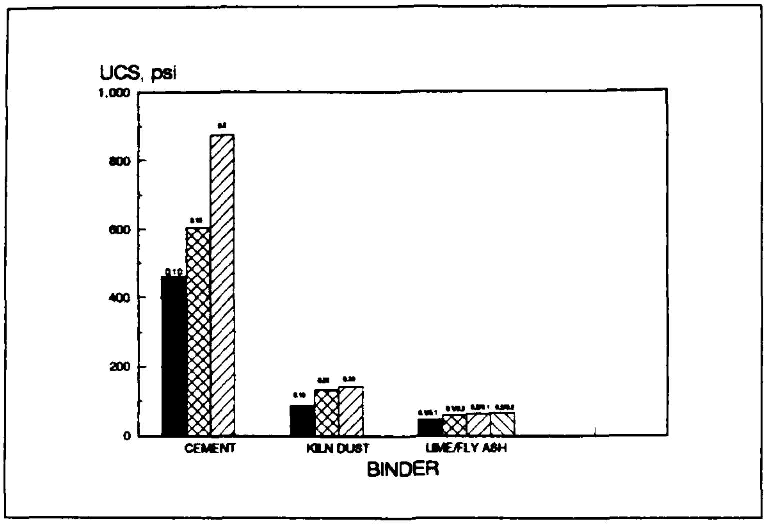


Figure 5. Twenty-eight day UCS for the S/S wood-preserving waste using cement, kiln dust, and lime/fly ash as binders

TCLP Results

The average results of the TCLP on the stabilized/solidified waste are presented in Table 9. Replicate results are presented in Appendix B. Arsenic and chromium were the metals of concern for the S/S of the soil. The regulatory limit for the TCLP extracts for both arsenic and chromium is 5.0 mg/ℓ. Appendix C presents the data for the TCLP performed on the binders used for this study.

After the samples were stabilized/solidified, the TCLP was performed on the samples and the leachate was analyzed for the TCLP metals. The 0.1 cement/0.0 water samples had a concentration of 8.87 mg/ℓ and 15.9 mg/ℓ for arsenic and chromium, respectively. The 0.1 kiln dust/0.0 water samples had a concentration of 32.13 mg/ℓ of arsenic and 20.00 mg/ℓ of chromium in the leachate. The 0.1 lime/0.2 fly ash/0.05 water samples had a concentration of 27.67 mg/ℓ of arsenic and 15.53 mg/ℓ of chromium in the leachate. Although cement treatment appeared to be the most effective binder system, the criteria of 5.0 mg/ℓ for arsenic and chromium for the TCLP concentration were not met. All of the treated samples failed to meet the regulatory criteria for the TCLP.

4 Conclusions

Based on the results of laboratory evaluations of the S/S techniques, the following conclusions can be made:

a. Binder-to-waste ratios of 0.1 portland cement, 0.1 kiln dust, and 0.1 lime/0.2 fly ash produce materials with UCS above the 50-psi criterion.

b. Water addition is not required for hydration in the cement and the kiln dust mixtures; however, water is necessary for hydration at the 0.1/0.2 lime/fly ash ratios.

c. The binders can be easily mixed with the soils.

d. The stabilized/solidified waste is free-standing with the observance of no free liquid.

e. The S/S process was not effective in reducing the mobility of arsenic and chromium to the regulatory levels of 5.0 mg/ℓ in the TCLP extract. However, the physical handling properties were improved.

References

American Society for Testing and Materials. (1986). "Construction; cement; lime; gypsum." Vol 0401, *Annual bank of ASTM standards*, Philadelphia, PA.

Headquarters, Department of the Army. (1971). "Materials testing," Technical Manual No. 5-530, Section XV, Washington, DC.

Iadevaia, R., and Kitchens, J. F. (1980). "Engineering and development support of general Decon technology and the DARCOM Installation Restoration Program, Task 4," Draft Report, Atlantic Research Corporation, Alexandria, VA.

Malone, P. G., and Jones, L. W. (1979). "Survey of solidification/stabilization and technology for hazardous industrial wastes," EPA-600/2-79-056, U.S. Environmental Protection Agency, Cincinnati, OH.

Malone, P. G., Jones, L. W., and Larson, R. J. (1980). *Guide to the disposal of chemically stabilized and solidified waste.* SW-872, Office of Water and Waste Management, U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. (1986a). "Best demonstrated available technology (BDAT) background document for F001-F005 spent solvents," EPA 1530-SW-86-056, Vol I, Office of Solid Waste, Washington, DC.

_________. (1986b). *Federal Register.* Vol 51, No. 142, Office of Solid Waste, Washington, DC.

_________. (1986c). *Handbook for stabilization/solidification of hazardous wastes.* Hazardous Waste Engineering Research Laboratory, Cincinnati, OH.

_________. (1986d). "Hazardous waste management system; land disposal restrictions; final rule." *Federal Register.* Part II, Vol 40 CFR Part 261 et Seq., Washington, DC.

U.S. Environmental Protection Agency. (1986e). "Prohibition on the placement of bulk liquid hazardous waste in landfills; statutory interpretive guidance," EPA 530 SW-86-016, OSWER Policy Directive 9487.00-24, Office of Solid Waste and Emergency Response, Washington, DC.

__________. (1986f). *Test methods for evaluating solid waste: Physical/chemical methods*. SW-846, 3rd ed., Office of Solid Waste and Emergency Response, Washington, DC.

Table 1
Compositional Analyses of the Binder Materials

Compositional Analysis	Cement Type I %	Lime %	Fly ash Class F %	Kiln Dust %
SiO_2	20 47	0 40	49 67	6 94
Al_2O_3	5 40	0 57	29 15	4 23
Fe_2O_3	3 58	0 16	7 11	1 47
CaO	64 77	72 27	1 26	62 93
MgO	0 87	0 65	1 43	0 44
SO_3	2 73	0 02	0 23	7 01
Insoluble residue	0 17	0 24	70 70[a]	3 09
Moisture loss	0 43	0 41	0 12[b]	0 05
Loss on ignition	0 96	24 04	4 07	14 08
TiO	0 28	0 01	0 20	0 11
Mn_2O_3	0 06	0 00	0 00	0 00
P_2O_5	0 28	0 02	1 00	0 05
Total alkali				
Na_2O	0 12	0 01	0 23	0 25
K_2O	0 28	0 00	2 33	0 40
Na	0 05	0 004	0 10	0 10
K	0 11	0 00	0 97	0 17
Total as Na_2O	0 30	0 01	1 76	0 51
Acid soluble alkali				
Na_2O	0 12	0 01	0 06	0 25
K_2O	0 28	0 00	0 50	0 40
Na	0 05	0 004	0 03	0 10
K	0 11	0 00	0 21	0 17
Water soluble alkali				
Na_2O	0 018	0 0033	0 050	0 021
K_2O	0 139	0 0220	0 105	0 050
Na	0 0075	0 0013	0 0210	0 008
K	0 0577	0 0091	0 0440	0 0208

[a] Insoluble residue includes SiO_2
[b] Free water

Table 2
Chemical Analyses of the Binder Materials

Chemical Analysis	Cement Type I mg/kg	Kiln Dust mg/kg	Lime mg/kg	Fly Ash Class F mg/kg
Si	95,700	1,900	232,200	32,400
S (total)	10,800	700	1,700	31,200
Ti	1,400	50	1,000	600
P	900	60	3,200	200
Sb	<1.77	<1.63	<1.77	13.3
As	13.1	14.7	6.74	172
Be	2.13	4.24	<1.77	28.9
Cd	0.284	2.28	0.639	1.01
Cr	61.3	30.0	14.6	139
Cu	14.9	12.7	<0.355	196
Pb	2.13	15.6	<0.355	57.7
Hg	<0.100	<0.100	<0.100	<0.100
Ni	25.9	33.6	6.39	190
Se	<17.7	<16.3	<17.7	<19.5
Ag	<3.54	<3.54	<3.54	<3.54
Tl	<10.6	<9.78	<10.6	13.6
Zn	41.8	107	17.7	211
Al	23,100	13,500	238	150,000
Ba	178	119	<3.55	1,350
Ca	454,000	440,000	500,000	12,000
Cd	10.6	<9.78	10.6	77.2
Fe	25,400	14,800	1,070	50,700
Mg	5,460	3,040	2,700	6,040
Mn	503	64.2	48.6	156
Na	1,270	2,110	110	2,740
Sn	195	73.0	74.5	118
V	55.6	34.6	11.7	351

Table 3
Matrix of Specimens Prepared for Initial Waste/Binder Screening

Binder/Waste Ratio	Number of Specimens at Indicated Water/Waste Ratio		
	0.0	0.05	0.1
Binder: Cement			
0.1	1	No sample	No sample
0.2	1	1	1
0.4	No sample	1	1
0.6	No sample	1	1
Total = 8 specimens			
Binder: Kiln Dust			
0.1	1	No sample	No sample
0.2	1	1	1
0.4	No sample	1	1
0.6	No sample	1	1
Total = 8 specimens			
Binder: Lime, Fly Ash			
0.1, 0.1	1	1	1
0.1, 0.3	No sample	1	1
0.2, 0.1	No sample	1	1
0.2, 0.2	No sample	1	1
Total = 9 specimens			

Table 4
Summary of S/S Process Batches Prepared In the Detailed Evaluation

Binder-to-Waste Description		Replicates		
Code	**Ratio**	**Run 1**	**Run 2**	**Run 3**
Cement/Waste[1]				
A	0.10	C.1.A	C.2.A	C.3.A
B	0.15	C.1.B	C.2.B	C.3.B
C	0.20	C.1.C	C.2.C	C.3.C
Kiln Dust/Waste[1]				
D	0.10	KD.1.D	KD.2.D	KD.3.D
E	0.20	KD.1.E	KD.2.E	KD.3.E
F	0.30	KD.1.F	KD.2.F	KD.3.F
Lime/Waste[2], Fly Ash/Waste[2]				
G	0.10, 0.10	L/F.1.G	L/F.2.G	L/F.3.G
H	0.10, 0.20	L/F.1.H	L/F.2.H	L/F.3.H
I	0.20, 0.10	L/F.1.I	L/F.2.I	L/F.3.I
J	0.20, 0.20	L/F.1.J	L/F.2.J	L/F.3.J

[1] No water was added to any of the cement or kiln dust mixtures
[2] A 0.05-percent water-to-waste ratio was added to the lime/fly ash mixtures

Table 5
Initial Screening Test Results: Cement Binder

Water Ratio	Cement Ratio	48-hr Cone Index Value, psi
0.0	0.1	>750
0.0	0.2	>750
0.05	0.2	>750
0.05	0.4	>750
0.05	0.6	>750
0.10	0.2	>750
0.10	0.4	>750
0.10	0.6	>750

Table 6
Initial Screening Test Results: Kiln Dust Binder

Water Ratio	Kiln Dust Ratio	48-hr Cone Index Value, psi
0.0	0.1	226
0.0	0.2	450
0.05	0.2	183
0.05	0.4	>750
0.05	0.6	>750
0.10	0.2	60
0.10	0.4	400
0.10	0.6	>750

Table 7
Initial Screening Test Results: Lime/Fly Ash Binder

Water Ratio	Lime Ratio	Fly Ash Ratio	48-hr Cone Index Value, psi
0.0	0.1	0.1	178
0.05	0.1	0.1	161
0.05	0.1	0.3	600
0.05	0.2	0.1	400
0.05	0.2	0.2	700
0.10	0.1	0.1	60
0.10	0.1	0.3	160
0.10	0.2	0.1	180
0.10	0.2	0.2	153

Table 8
Binder Ratios Selected for TCLP Extraction

Binder	BWR Selected	Water Ratio
Cement	0 1	0.0
Kiln dust	0 1	0 0
Lime/fly ash	0 1/0 2	0.05

Table 9
Average[1] TCLP Extract Concentrations for the S/S Wood-Preserving Waste

Contaminant	Concentration (mg/ℓ) Binder System/BWR/WWR		
	Cement 0.1 BWR 0.0 WWR	Kiln Dust 0.1 BWR 0.0 WWR	Lime/Fly Ash 0.1/0.2 BWR 0.05 WWR
Arsenic	8 87	32 13	27.67
Barium	0 484	0 705	0 607
Cadmium	0 0011	0 0002	<0 0001
Chromium	15 90	20 00	15 53
Lead	0 0207	0 028	0 0019
Mercury	0 0012	0 0020	0 0019
Selenium	<0 005	<0 005	<0 005
Silver	<0 0010	<0 0010	<0 0010

[1] Average of replicates in Table 8

Appendix A Unconfined Compressive Strength Data

This appendix contains the results of the unconfined compressive strength (UCS) testing. The UCS for each cube prepared during this evaluation is provided. Table A1 presents the UCS results for the wood-preserving waste S/S with cement; Table A2 presents the UCS results for the wood-preserving waste S/S with kiln dust; Table A3 presents the UCS results for the wood-preserving waste S/S with lime/fly ash.

Table A1
UCS Results for the Wood-Preserving Waste Cement Binder

Cement Ratio	Subsample ID	Cure Time, days	UCS, psi
0.10	A	7	489
	B	7	525
	C	7	341
0.10	A	14	774
	B	14	723
	C	14	727
0.10	A	21	522
	B	21	487
	C	21	364
0.10	A	28	481
	B	28	532
	C	28	368
0.15	A	7	547
	B	7	657
	C	7	340
0.15	A	14	613
	B	14	654
	C	14	487
0.15	A	21	637
	B	21	752
	C	21	470
0.15	A	28	622
	B	28	729
	C	28	464
0.20	A	7	767
	B	7	750
	C	7	731
0.20	A	14	538
	B	14	535
	C	14	378
0.20	A	21	884
	B	21	909
	C	21	883
0.20	A	28	916
	B	28	849
	C	28	857

Table A2
Raw UCS Results for the Wood-Preserving Waste Kiln Dust Binder

Kiln Dust Ratio	Subsample ID	Cure Time, days	UCS, psi
0 10	A	7	49
	B	7	42
	C	7	41
0 10	A	14	73
	B	14	72
	C	14	71
0 10	A	21	93
	B	21	67
	C	21	66
0 10	A	28	91
	B	28	83
	C	28	87
0 20	A	7	49
	B	7	60
	C	7	55
0 20	A	14	95
	B	14	110
	C	14	100
0 20	A	21	113
	B	21	145
	C	21	120
0 20	A	28	119
	B	28	150
	C	28	121
0 30	A	7	57
	B	7	72
	C	7	79
0 30	A	14	116
	B	14	125
	C	14	119
0 30	A	21	129
	B	21	162
	C	21	161
0 30	A	28	121
	B	28	135
	C	28	165

Table A3
Raw UCS Results for the Wood-Preserving Waste Lime/Fly Ash Binder

Lime Ratio	Fly Ash Ratio	Subsample ID	Cure Time days	UCS, psi
0.10	0.10	A	7	46
		B	7	36
		C	7	34
0.10	0.10	A	14	55
		B	14	42
		C	14	47
0.10	0.10	A	21	43
		B	21	43
		C	21	40
0.10	0.10	A	28	50
		B	28	45
		C	28	44
0.10	0.20	A	7	45
		B	7	53
		C	7	55
0.10	0.20	A	14	59
		B	14	55
		C	14	63
0.10	0.20	A	21	59
		B	21	59
		C	21	68
0.10	0.20	A	28	56
		B	28	64
		C	28	60
0.20	0.10	A	7	73
		B	7	63
		C	7	48
0.20	0.10	A	14	65
		B	14	64
		C	14	47
0.20	0.10	A	21	68
		B	21	65
		C	21	51

(Continued)

Table A3 (Concluded)				
Lime Ratio	**Fly Ash Ratio**	**Subsample ID**	**Cure Time days**	**UCS, psi**
0 20	0.10	A	28	69
		B	28	66
		C	28	53
0 20	0.20	A	7	72
		B	7	60
		C	7	57
0 20	0.20	A	14	70
		B	14	55
		C	14	57
0.20	0.20	A	21	74
		B	21	56
		C	21	58
0 20	0.20	A	28	77
		B	28	57
		C	28	60

Appendix B
Toxicity Characteristic Leaching Procedure Data

This appendix contains the results of the chemical analyses of the Toxicity Characteristic Leaching Procedure (TCLP) extracts.

Table B1
TCLP Leachate Concentrations for the S/S Wood-Preserving Waste

Binder	Sample	TCLP Concentration, mg/ℓ							
		Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
Cement	A	8.91	0.421	<0.0004	15.8	<0.020	0.0016	<0.005	<0.0010
	B	9.27	0.393	0.0012	16.0	<0.020	0.0010	<0.005	<0.0010
	C	8.42	0.639	0.0016	15.9	0.022	0.0009	<0.005	<0.0010
Kiln Dust	A	31.0	0.723	0.0004	17.7	0.026	0.0022	<0.005	<0.0010
	B	32.4	0.645	<0.0001	18.1	0.023	0.0018	<0.005	<0.0010
	C	33.0	0.748	<0.0001	24.2	0.036	0.0020	<0.005	<0.0010
Lime/Fly Ash	A	27.9	0.0158	<0.0001	15.9	<0.020	0.0020	<0.005	<0.0010
	B	27.1	0.0551	<0.0001	15.8	0.025	0.0019	<0.005	<0.0010
	C	28.0	0.715	<0.0001	14.9	<0.020	0.0017	<0.005	<0.0010

Table B2
Quality Control/Quality Assurance Data for the S/S Wood-Preserving Waste Replicate Analysis

Binder	Sample	TCLP Concentration, mg/ℓ							
		Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
Cement	A	8 82	0 419	<0 0004	15 7		0 0016	<0 005	<0 0010
Cement	C	8 46	0 639	NO SAMP	15 8	<0 020	NO SAMP	NO SAMP	0 0010
Cement	Blank	0 040	0 154	0 0024	0 016	<0 020	<0 0002	<0 005	<0 0010
Kiln Dust	Blank	0 044	0 158	<0 0001	<0 005	<0 020	<0 0002	<0 005	<0 0010
Lime/Fly Ash	A	27 9	0 548	<0 0001	15 9	NO SAMP	0 0020	NO SAMP	<0 0010
Lime/Fly Ash	Blank	0 052	0 176	<0 0001	[illegible]	<0 020	<0 0002	<0 005	<0 0010

Note NO SAMP = No Sample Taken

Table B3
Quality Control/Quality Assurance Data for the S/S Wood-Preserving Waste Percent Recovery Analyses

Binder	Sample	Contaminant, mg/ℓ							
		Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
Cement	A	91 0	110 0	100 0	77 5	*	98 0	44 0	107 0
Cement	C	110 0	10 9	*	*	98 8	*	*	106 2
Lime/Fly Ash	A	112 0	*	*	*	*	98 0	*	101 0

Note * = Sample not spiked with analyte

Appendix C Binder Toxicity Characteristic Leaching Procedure Results

This appendix presents the analyses of the Toxicity Characteristic Leaching Procedure (TCLP) performed on the binders utilized to stabilize/solidify the wood-preserving wastes. The results for the triplicate analyses of the binders (cement, kiln dust, and lime/fly ash) are given in Table C1.

Table C1
Binder TCLP Leachate Concentrations

Binder	Sample	TCLP Concentration, mg/ℓ										
		Ag	At	Al	As	Cd	Cr	Cu	Hg	Ni	Pb	Se
Cement	A	0 035	<0 005	0 599	<0 005	0 0001	0 334	0.001	<0 0004	0 002	0.006	<0.050
	B	0 039	<0 005	0 702	0 006	<0 0001	0 307	0.001	<0 0004	0 002	0.002	<0 050
	C	0 037	<0 005	0 596	0 005	0 0001	0 300	0.001	<0 0004	<0 001	0 002	<0 050
Average		0 037	<0 005	0 632	0 004	0.0001	0 314	0.001	<0 0004	0 0015	0 002	<0 050
Kiln Dust	A	<0 010	<0 005	0 642	0.008	0 001	0 060	0.001	<0 0008	0 002	0.032	<0.050
	B	<0 010	<0 005	0 619	0 005	<0 0001	0.057	0.001	<0 0004	0 002	0 038	<0.050
	C	0 013	0 005	0 615	0.007	0.0001	0 057	0 001	<0 0004	0.004	0 044	<0 050
Average		0 008	<0 005	0 625	0 0066	0 0004	0 058	0.001	<0 0004	0 0026	0 038	<0.050
L/F'	A	<0 010	<0 005	0 716	0.014	0.0002	0 033	0 003	<0 0004	0 002	0.008	<0.050
	B	<0 010	<0 005	0 654	0.020	<0.0001	0 024	0 008	<0.0004	<0 001	0.006	<0.050
	C	0 019	<0 005	0 515	0.008	0.0001	0 022	0 006	<0 0004	<0 001	0.006	<0.050
Average		0 010	<0 005	0 628	0 014	0 0001	0.026	0 0056	<0.004	0 001	0.007	<0 050

' L/F = Lime/Fly Ash

(Continued)

Table C1 (Concluded)

Binder	Sample	TCLP Concentration, mg/l										
		Th	Zn	Tn	Ba	Ca	Cd	Fe	Mg	Mn	Na	Va
Cement	A	0 031	<0 030	<0 200	1 06	3,340	<0 030	0 134	<0 030	0 095	12 8	<0 005
	B	<0 030	<0 030	<0 200	1 09	3,310	<0 030	0 144	0 059	0 098	12 6	<0 005
	C	<0 030	<0 030	<0 200	0 906	3,370	<0 030	0 071	0 030	0.095	12 6	<0 005
Average		0 011	<0 030	<0 200	1 019	3 340	<0 030	0 166	0 030	0 096	12 67	<0 005
Kiln Dust	A	<0 030	0 093	<0 200	0 549	3,160	<0 030	0 098	0 055	0 096	22 2	<0 030
	B	0 034	0 037	<0 200	0 613	3,160	<0 030	0 087	0 047	0 099	22 8	<0 005
	C	<0 030	0 036	<0 200	0 698	3,260	<0 030	0 078	0 069	0 103	22 9	<0 005
Average		0 012	0 055	<0 200	0 620	3,193	<0 030	0 088	0 057	0 099	22 6	<0 0006
L/F[1]	A	<0 030	0 040	<0 200	2 17	2,820	<0 030	0 054	<0 030	0 077	6 06	<0 030
	B	<0 030	0 036	<0 200	2 13	2,630	<0 030	0 089	<0 030	0 077	6 50	<0 030
	C	<0 030	0 100	0 200	2 36	2,500	<0 030	0 064	<0 030	0 070	6 88	<0 030
Average		<0 030	0 029	<0 200	2 22	2,650	<0 030	0 069	<0 030	0 077	6 48	<0 030

[1] L/F = Lime/Fly Ash

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1993	Final report

4. TITLE AND SUBTITLE

An Evaluation of Stabilization/Solidification of an Inorganic Wood-Preserving Waste

5. FUNDING NUMBERS

6. AUTHOR(S)

Michael G. Channell
Teresa T. Kosson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

Technical Report
EL-93-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Technical Evaluation and Development Section
Cincinnati, OH 45268

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report presents the results of testing performed on a stabilized/solidified (S/S) inorganic wood-preserving waste. The contaminants found in the waste are primarily arsenic and chromium. Three S/S processes were evaluated in this study. They include the following: (a) a cement process, (b) a kiln dust process, and (c) a lime/fly ash process. Physical and leaching characteristics of the S/S waste materials were evaluated. Physical characteristics were evaluated using the unconfined compressive strength test. The waste-leaching characteristics were evaluated using the toxicity characteristic leaching procedure (TCLP). Physical test results showed that S/S waste developed 28-day strengths ranging from 44 to 916 psi. Results of the chemical leach tests showed that S/S did reduce the amount of arsenic and chromium found in the extract, but the levels were not met for the TCLP test.

14. SUBJECT TERMS

Contaminant immobilization
Hazardous waste
Solidification
Waste disposal
Wood preserving

15. NUMBER OF PAGES

42

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		