USE OF IMAGE ANALYSIS FOR EVALUATING CONCRETE AS A WASTE ISOLATION MEDIUM

Dr. William F. Buckingham, Dr. Joan Spaw
Everest Geotech Company
Houston, Texas 77074

E. Benjamin Peacock
Wastech, Inc.
Oak Ridge, Tennessee

ABSTRACT

A technique has been developed, tested and is presently being used for disposing of contaminated soil by incorporating the soil into a concrete matrix. A concrete mix is produced consisting of contaminated soil, portland cement and class F fly ash. Following a chemical process which fixes organic and metallic contaminants to the soil particles, the concrete mixture is poured on site as a monolith, replacing the excavated soil.

During the course of the project, leaching procedures (ANS 10.1 MCC 1), permeability and compressive strength tests are performed. The quality of the mix and the blending process are ensured by examining the hardened concrete using a quantitative image analysis system. The concrete is thin sectioned and impregnated with a dyed epoxy. A computer image of the thin section is analyzed and the percentage of each solid phase and porosity is measured. Distribution of the contaminated soil in the sample is mapped along with the occurrence of porosity. Multiple samples are analyzed to determine the degree of heterogeneity in the sample. In acceptable samples, the soil occurs as isolated islands less than 1 mm across, in a matrix of portland cement. Porosity is restricted to non-soil zones, lowering the possibility of leaching by percolating ground water. Porosity does not form along soil/cement boundaries indicating good adhesion between these two phases. Fluid flow modeling is performed on the computer images. The model allows an analyst to observe the likeliest pathways which a percolating fluid will travel through the sample. It also allows relative flow rates to be ascertained. Analysis of the modeling results indicate a direct relationship between sample texture and permeability.

The results of this study show image analysis to be a viable technique for quality control of concrete mixes as well as a tool in mix design.

INTRODUCTION

In order to ensure the environmental safety of cement as an isolation device for waste, numerous tests are prescribed. The tests are designed to ensure the mechanical strength and the inability of the waste to leach into the local environment. Short term leachate tests are extrapolated to thousand-year time scales to insure that the environment is protected in both the short and long term.

An assumption was made that the strength of cement grout, its chemical stability, and its resistance to leaching were related to both the amount of each component present in the mix and the geometric arrangement of those components in the hardened mix. A high degree of edge-to-edge contacts in hardened cement paste would produce a strong cement lattice with high compressive strength. A homogeneous mixture which produced little interconnectedness between waste-rich zones and porosity would result in a low probability of percolating water contacting sources of leachate.

From this hypothesis, it becomes apparent that mechanical and leaching tests were derivative measurements; not truly measuring the controlling parameters, but measuring an effect of the controlling parameters. The measurements necessary to optimize the mix formula before the monolith is poured are composition and texture.

PROCEDURE

In order to measure the composition and texture, a specially-designed, computerized analytical system was used. Samples of nine waste-entrained concrete mixes, in which the waste was PCB and metal-contaminated soil, were specially prepared for analysis. The nine mixes were poured into three-by-six-inch cylinders and aged greater than 28 days.

Thin sections were prepared by removing slices 3 mm thick from each cylinder. The slices were epoxy-impregnated and mounted on microscope slides. The slices were ground and polished to a thickness of 30 micrometers. The impregnated epoxy was mixed with Rhodamine B dye, producing an overall pink or magenta coloration.

The thin sections were examined in transmitted light on a binocular microscope. Full color computer images were created by scanning each sample with a solid-state camera mounted on the microscope port. Two scenes were collected from each sample. One scene was an average view for the sample; the other was collected from an area which varied greatly from the average.

The resulting images were analyzed using a specially-designed software package which allows the analyst to select groups of colors that are characteristic of each component. The software then locates all particles of cement, porosity, soil, Class F fly ash, sand, wood fragments, and organic soil constituents. Soil, wood fragments, and organic soil constituents were grouped together because they are all original constituents in the contaminated soil.

A separate computer image is then created to map each component: a soil image, sand image, porosity image, and cement image. The separate maps, called component images, contain the boundaries and the spatial location of each particle of the component being separated. Analysis was performed on each of the separate component images.

ANALYTICAL RESULTS

Of the nine samples examined, the two extreme examples are presented here for discussion. Sample PW5A is a homogeneous sample in which the contaminated soil is distributed evenly throughout the sample. Prior testing showed that this sample has acceptable compressive strength, low permeability, and low leachate content of PCB's, Pb, and Cd. Sample PD3B is a poor sample with heterogeneous texture and a permeability two orders of magnitude greater than sample PW5A.

Computer images of the two samples are included as Figs. 1 and 2. Initially, the two samples appear quite similar. The overall magenta color is due to the dye in the impregnated epoxy. The darkest areas are soil constituents, including plant and wood fragments. The brightest pink areas are open pores. The medium pink areas are cement and the white grains are sand and silt derived from the soil. Class F fly ash, due to its dark color, is not easily discernible from organic soil constituents and must be discriminated by its spherical shape later in the analytical procedure. Overall, visual inspection leads to the conclusion that the two samples are quite similar.

Further inspection proves this to be untrue. As mentioned previously, the analytical procedure produces individual images of the boundaries and location of each component. Figures 3 and 4 are two such component images. Figure 3 illustrates the spatial distribution of soil in PW5A, the acceptable sample. The figure depicts the boundaries of all the individual soil particles in the sample.

Statistical data produced by image quantification software at this step, and recorded in Table I, show the soil in PW5A to be distributed in 1270 individual particles. The particles cover 24% of the area of the sample and they have a mean size of .00497 mm^2. Sample PD3B provides quite a contrast. Its soil component image (Fig. 4) shows an interconnected, convoluted boundary which covers the entire sample.

The soil statistics for PD3B, again from Table I, show soil covering 64% of the total area. This is over 2.5 times the amount of soil in PW5A. The soil is distributed in a few number (97 vs. 1270) of very large (mean size = .173 mm^2) particles. On the basis of soil distribution alone, these samples are quite dissimilar.

A second major difference is the distribution of cement in the two samples. Sample PW5A contains 55% cement distributed in 339 particles with a mean size of .04238 $mm^{2.}$ The spatial distribution of cement is illustrated in Fig. 5. Sample PD3B contains only 13% cement. The cement is distributed in 1691 objects with a mean size of .0021 mm^2. Fig. 6 depicts the distribution of cement in PD3B.

Comparison of Fig. 5 with Fig. 6 and Fig. 3 with Fig. 4 shows a major difference between the two samples. Sample PW5A (Figs. 3 and 5) consists of a "sea" of cement in which all other components reside. The cement forms one large convoluted object wrapping around all other objects. The soil in PW5A (Fig. 3) occurs as islands in a cement sea. The islands, while numerous, are isolated, allowing little in the way of a permeable pathway for leaching fluids. PD3B, on the other hand, is a mirror image of PW5A. The soil occurs as a continuous convoluted object (Fig. 4) in which the pores, sand grains, and cement float. The cement occurs as a group of numerous, small, isolated islands (Fig. 6).

From image analysis, it can be seen that PW5A is a homogeneous cement. Porosity is restricted to the cement regions. Individual soil zones are isolated from porosity and from other soil zones. The framework of the sample is hardened cement. This provides a high compressive strength and reduces the chances of failure and fracture development. Sample PD3B is quite different. Soil forms the matrix holding the sample together. Pores are in close proximity to the waste-containing soils. Cement occurs as isolated islands. Compressive strength is low since soil would have to sustain any applied load. Downward percolating fluids would have access to a long flow path in contact with contaminant-releasing soils.

CONCLUSIONS

The present study is meant to be preliminary rather than conclusive. It was shown that components relating to the quality of waste-isolation cements can be quantified by both amount and distribution. The relationship between texture and bulk properties (leachate content, compressive strength) can be hinted at, but any proposed quantitative relationships will be the result of many more analyses. The present study illustrates the abilities of quantitative image analysis in exploring complex behavior.

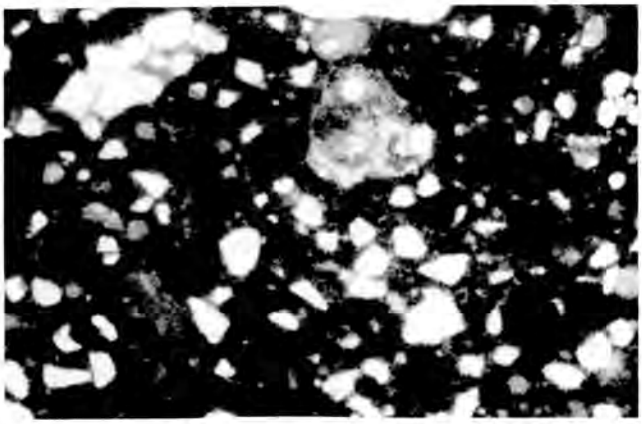

Fig. 1. Computer Image of Sample PW5A (Original in Color).

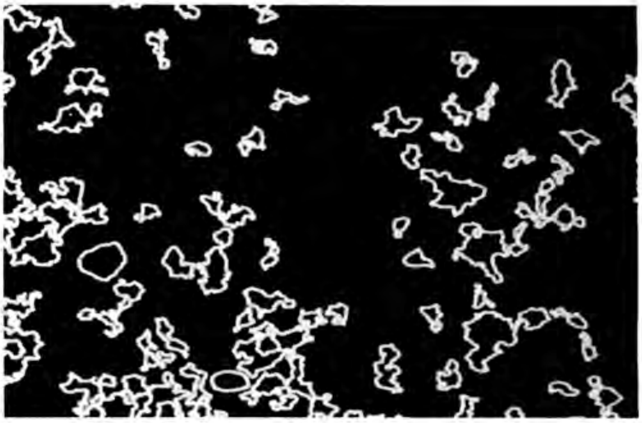

Fig. 3. Boundary Map of Contaminated Soil in Sample PW5A.

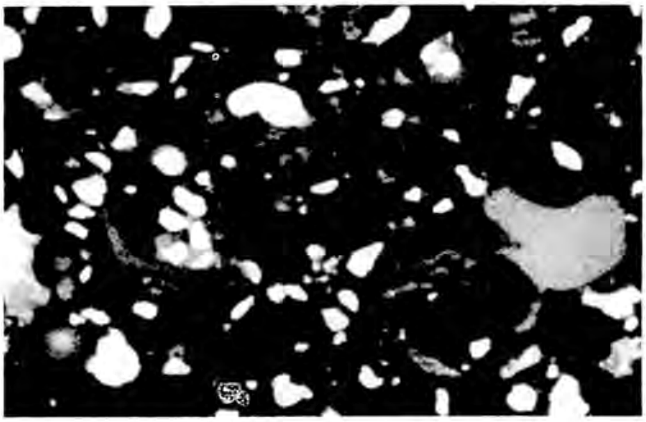

Fig. 2. Computer Image of Sample PD3B (Original in Color).

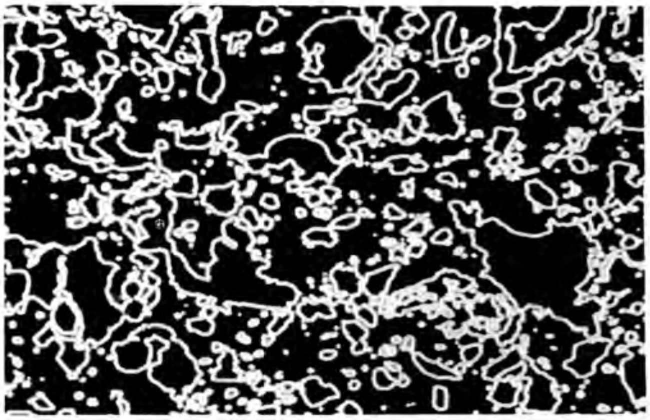

Fig. 4. Boundary Map of Contaminated Soil in Sample PD3B.

TABLE I

Statistics Derived from Computer Images of Samples PW5A and PD3B

SAMPLE	COMPONENT	NUMBER OF PARTICLES	PARTICLE SIZE (mm)	MEAN SIZE SD
PW5A	Porosity 3%	367	0.002416	0.008703
	Cement 55%	339	0.04238	0.7595
	Soil 24%	1270	0.00497	0.0216
	Sand 14%	430	0.00838	0.0287
PD3B	Porosity 6%	394	0.0042	0.0231
	Cement 13%	1691	0.0021	0.0072
	Soil 64%	97	0.173	1.6955
	Sand 14%	452	0.0078	0.028

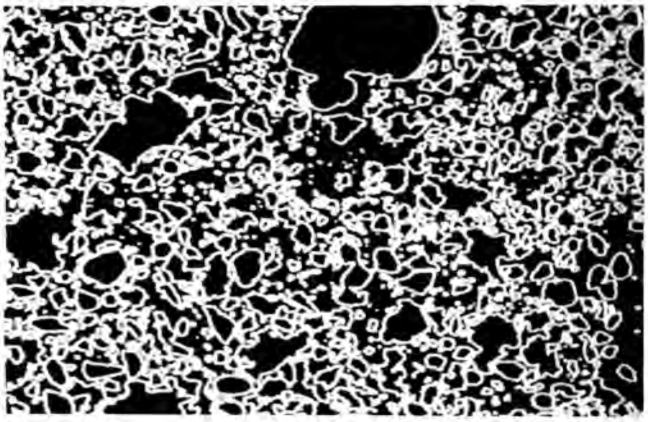

Fig. 5. Boundary Map of Cement Zones in Sample PW5A

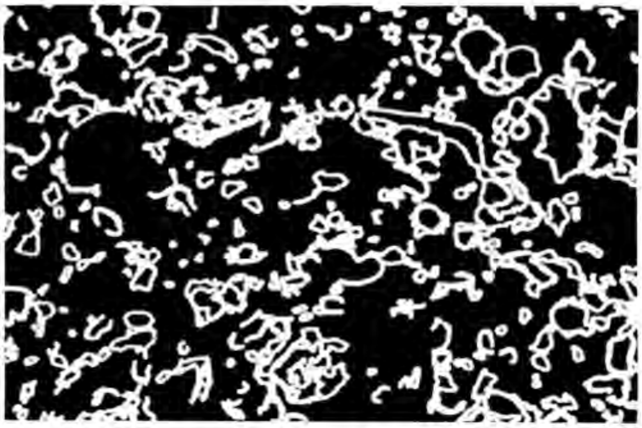

Fig. 6. Boundary Map of Cement Zones in Sample PD3B.

In this study, image analysis was used to test homogeneity after the monolith was poured. The ultimate value of these tests, however, will be to apply them during the mix design phase. Image quantification could provide the mix engineer with precise determinations of the mix parameters, tailored to the waste composition variables. This would enable production of the lowest cost concrete with the appropriate strength and leaching properties to meet environmental safety specifications.