Use of Foundry Sands in Transportation Applications

Project Report No. 7-4935-1

Final Report

Texas State Department of Transportation

by

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The study was conducted in cooperation with the U. S. Department of Transportation and Federal Highway Administration.

16. Abstract

The primary objective of this project was to verify the availability and suitability of Texas-generated foundry sand (FS) for TxDOT and to develop specifications for use of these sands in TxDOT construction and maintenance applications. Extensive literature review was undertaken to collect information on the potential foundry sand applications, case studies on foundry sand use, engineering and environmental properties of foundry sand, relevant regulations and specifications. The information was synthesized to determine the two potential applications for foundry sand in Texas.

From the Texas foundry survey it was determined that over 93,000 tons of foundry sand is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There are over 3.3 million tons of foundry sand in stock piles in Texas. A total of ten foundry sands were randomly collected from around the State of Texas for the laboratory study. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. Particle size of all the Texas foundry sand tested was finer than that of ASTM C-33 sand. The pH of the FS varied from 7 to 10.2. Few foundry sands were tested using the EPA (including the TCLP) and TNRCC (presently known as TCEQ) leaching tests. The engineering and environmental properties of the Texas foundry sands were within the range of values reported in the literature.

Material specification for foundry sand and a MSDS sheet have been developed. Based on the TxDOT needs and the properties of the foundry sands, it's potential use in flowable fill and cemented sand was investigated. Design approaches for flowable fill and cemented sand mixes have been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio. More than two hundred laboratory and field specimens were tested for a period of over one year. Laboratory and field test results indicated that the foundry sand can be used in flowable fill and cemented sand applications. Foundry sand selected for use should satisfy the DMS-11000 guidelines for Nonhazardous Recyclable Material (NRM).

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

The primary objective of this project is to verify the availability and suitability of Texas-generated FS for TxDOT and to develop specifications for use of these sands in TxDOT construction and maintenance applications. Based on the TxDOT needs, use of foundry sand in flowable fill and cemented sand was investigated. A survey was undertaken with the collaboration of the TexaS Cast Metal Association to determine the availability of foundry sand in Texas. The study also included testing of number of foundry sand available in the State of Texas to determine their engineering and environmental properties and compare it to published data from other locations outside Texas. A detailed evaluation of flowable fill and cemented sand using the foundry sand in Texas was performed by combining laboratory tests and field applications. Field tests on the flowable fill and cemented sand were done in the Brownwood District and Houston District respectively.

Based on the survey it was determined that over 93,000 tons of foundry sand is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There is over 3.3 million tons of foundry sand in stock piles in Texas. Total of ten foundry sands were randomly collected from around the State of Texas for the laboratory study. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. Particle size of all the Texas foundry sand tested were finer than ASTM C-33 sand. The pH of the FS varied from 7 to 10.2. Few foundry sands were tested using the EPA (including the TCLP) and TNRCC leaching tests. The engineering and environmental of Texas foundry sands were within the range of values reported in the literature. Specification for foundry sand has been developed. MSDS sheet and material specification for Texas foundry sand has been developed. Design approaches for flowable fill and cemented sand mixes have been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio.More than two hundred labortory and field specimens have been tested over a year. Laboratory and field test results indicate that the foundry sand can be used for the selected applications. TxDOT specifications have been modified to include the foundry sand.

ABSTRACT

Foundry sand (FS) is a by-product of the metal casting industry that results from the molding and core-making processes. Research has shown that FS has the potential for use in highway construction and several other civil engineering applications. The primary objective of this project is to verify the availability and suitability of Texas-generated foundry sand for TxDOT projects and to develop specifications for use of these sands in construction and maintenance applications. A survey was undertaken with the collaboration of the TexaS Cast Metal Association to determine the availability of foundry sand in Texas. The study also included testing of number of foundry sand available in the State of Texas to determine their engineering and environmental properties and compare it to published data from other locations outside Texas. A detailed evaluation of flowable fill and cemented sand using the foundry sand in Texas was performed by combining laboratory tests and field applications. Field tests on the flowable fill and cemented sand were performed in the Brownwood District and Houston District respectively.

Based on the survey it was determined that over 93,000 tons of foundry sand is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There is over 3.3 million tons of foundry sand in stock piles in Texas. Total of ten foundry sands were randomly collected from around the State of Texas for the laboratory study. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. Particle size of all the Texas foundry sand tested were finer than ASTM C-33 sand. The pH of the FS varied from 7 to 10.2. Few foundry sands were tested using the EPA (including the TCLP) and TNRCC leaching tests. The engineering and environmental properties of Texas foundry sands were within the range of values reported in the literature. Material specification for foundry sand and a MSDS sheet have been developed. Based on the TxDOT needs and the properties of the foundry sands, it's potential use in flowable fill and cemented sand was investigated.Design approaches for flowable fill and cemented sand mixes have been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio.More than two hundred labortory and field specimens have been tested for a period of over one year. Property relationships for flowable fill and cemented sand have been developed by relating the pulse velocity and cement content to the compressive strength of the cured materials. Laboratory and field test results indicate that the foundry sand can be used for the selected applications. TxDOT specifications on flowable fill and cemented sand have been modified to include the foundry sand.

SUMMARY

Foundry sand (FS) is a by-product of the metal casting industry that results from the molding and core-making processes. The sands are reused a number of times, until they are so altered that they must be discarded. There are three types of molding process: greensand, chemically bonded, and shell molded. The most commonly used process is the greensand. In the greensand process clay is typically added as binding agent. The bulk of the FS is non-hazardous and is currently disposed in landfills. Several mid-western states such as Iowa, Indiana, Illinois, Michigan, Ohio and Wisconsin have investigated the use of FS in their transportation facilities. Research has shown that FS has the potential for use in highway construction and several other civil engineering applications. EPA's Final Rule in 40 CFR Part 247 (2000) is a comprehensive guideline for procurement of products containing recovered materials. The Final Rule includes the use of ferrous foundry sands in flowable fill. It must be noted that the EPA has removed any characterization of non-ferrous foundry sands as hazardous in the final Comprehensive Procurement Guideline (CPG).

The primary objective of this project is to verify the availability and suitability of Texas-generated foundry sand for TxDOT projects and to develop specifications for use of these sands in construction and maintenance applications. A survey was undertaken with the collaboration of the TexaS Cast Metal Association to determine the availability of foundry sand in Texas. The study also included testing of number of foundry sand available in the State of Texas to determine their engineering and environmental properties and compare it to published data from other locations outside Texas. A detailed evaluation of flowable fill and cemented sand using the foundry sand in Texas was performed by combining laboratory tests and field applications. Field tests on the flowable fill and cemented sand were performed in the Brownwood District and Houston District respectively.

Based on the literature review, some of the most popular applications for foundry sand are in roadway sub-base, embankment, asphalt concrete and flowable fill. Also number of other applications have been identified where foundry sand has been used. Foundry sand has not been used in cemented sand. Few state DOTs have specifications for using foundry sand in flowable fill mixes.

From the Texas foundry survey it was determined that over 93,000 tons of foundry sand is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There is over 3.3 million tons of foundry sand in stock piles in Texas. Total of ten foundry sands were randomly collected from around the State of Texas for the laboratory study. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. Particle size of all the Texas foundry sand tested were finer than ASTM C-33 sand. The pH of the FS varied from 7 to 10.2. Few foundry sands were tested using the EPA (including the TCLP) and TNRCC leaching tests. The engineering and environmental properties of the Texas foundry sands were within the range of values reported in the literature. Material specification for foundry sand and a MSDS sheet have been developed. Based on the TxDOT needs and the properties of the foundry sands, it's potential use in flowable fill and cemented sand was investigated. Design approaches for flowable fill and cemented sand mixes have been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio.More than two hundred labortory and field specimens have been tested for a period of over one year. Property relationships for flowable fill and cemented sand have been developed by relating the pulse velocity and cement content to the compressive strength of the cured materials. Laboratory and field test results indicate that the foundry sand can be used for the selected applications. TxDOT specifications on flowable fill (ITEM 4438-Flowable Backfill) and cemented sand (ITEM 400.6-Cement stabilized backfill for structures; ITEM 423.2- Backfill material for retaining wall) have been modified to include the foundry sand.

IMPLEMENTATION STATEMENT

This Report will be a guidance document to TxDOT engineers on the availability and suitability of Texas-generated foundry sand for TxDOT projects. Approach to evaluate the foundry sand has been outlined. Design approaches for flowable fill and cemented sand mixes have been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio. This document can be used as an initial data base on the available foundry sands in Texas.

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Chapter 1

INTRODUCTION

Foundry sand (FS) is a by-product of the metal casting industry that results from the molding and core-making processes. The sands are reused a number of times, until they are so altered that they must be discarded. There are three types of molding process: greensand, chemically bonded, and shell molded. The most commonly used process is the greensand. In the greensand process clay is typically added as binding agent [Javed et al., 1994]. The bulk of the FS is non-hazardous and is currently disposed in landfills costing between $20 to $40 per ton [Vipulanandan et al. 1998].

Key foundry states are California, Illinois, Indiana, Iowa, Michigan, Minnesota, Louisiana, Ohio, Pennsylvania, Texas and Wisconsin [Abichou et al. 1999; Vipulanandan et al. 1998]. The annual generation of FS in Indiana is about 450,000 tons (Mast et al. 1998) and in the U.S. is estimated to be about 15 million tons [Ezra Kotzin (Technical Expert, American Foundrymen's Society (AFS) Headquarters, IL), Personal communication]. In Texas, the private sector has been using the foundry sand in various small volume applications and the efforts in using it in transportation applications has not been well coordinated. No information is available on the availability of foundry sand in Texas or the amount of foundry sand in stockpiles that can be used in various transportation applications.

Several mid-western states such as Iowa, Indiana, Illinois, Michigan, Ohio and Wisconsin have investigated the use of FS in their transportation facilities [Abichou et al. 1998, 1999]. Research has shown that FS has the potential for use in highway construction and several other civil engineering applications. Javed et al. (1994) studied the potential use of FS in asphalt concrete and reported that a replacement level of 15% was suitable. FS is also used in embankment fills, subgrades and flowable fills (Naik et al. 1994; Bhat et al. 1996; Lovejoy et al. 1997; Abichou et al. 1998; EPA, CFR 247, 2000). Literature review also indicated that the greensand was the most popular of the FS and up to 35% have been used as replacement for conventional materials. The awareness about the environment over the past few decades has set a trend towards the usage and recycled materials in various applications [Bloomquist et al. 1993; FHWA/EPA, 1993; NCHRP, 1994].

EPA's Final Rule in 40 CFR Part 247 (2000) is a comprehensive guideline for procurement of products containing recovered materials. It is anticipated that the proposed action will foster markets for materials recovered from solid waste by using government purchasing power to simulate the use of these materials in the manufacture of new products (Federal Register/Vol. 65, No. 12, January 19, 2000). The final rule includes the use of ferrous foundry sands in flowable fill. According to the Federal Register/Vol. 65, No. 12, 20 percent of the FS generated annually currently are recovered and used. It also noted that while ferrous and non-ferrous foundry sands can be used in flowable fill mixtures, typically non-ferrous foundry sands may have to be evaluated in more detail due to their lead and cadmium contents (63 FR 45563). It must be noted that the EPA has removed any characterization of non-ferrous foundry sands as hazardous in the final Comprehensive Procurement Guideline (CPG). EPA's designation does not change the regulatory management of the recovered materials (such as foundry sand) nor does it exempts the material from existing waste management regulations. According to EPA, the determination as to whether the ferrous foundry sands contain contaminants at regulatory levels should be made in accordance with the applicable federal and state regulations before the material is used to make a commercial product (Appendix A).

Research in other parts of the country indicates that foundry sand has the potential to be beneficially, safely, and cost-effectively used in road construction. The primary objective of this project is to verify these results for Texas-generated FS, to investigate the economical/environmental suitability of FS use for TxDOT and to develop specifications for use of these sands in TxDOT construction and maintenance applications.

1. 1 OBJECTIVES

The primary objective of this project is to verify these results for Texas-generated FS, to investigate the economical/environmental suitability of FS use for TxDOT and to develop specifications for use of these sands in TxDOT construction and maintenance applications. The specific objectives of the proposed research are as follows:

(1) To conduct an extensive literature review to investigate and document potential uses for FS in various construction, maintenance and rehabilitation. The literature review was focused on collecting information such as (a) potential applications for FS in transportation facilities and methods of constructions; (b) experiences of other SDOTs, (c) availability of FS on a statewide basis, and (d) regulations and specifications on FS. Based on the information collected and the needs of TxDOT, identify applications for FS in Texas.

(2) To perform limited laboratory tests to supplement the information in the literature on FS and to specifically evaluate material available in Texas.

(3) To demonstrate the performance of FS in selected field applications.

(4) To develop specifications for FS applications with QA/QC plan for testing FS.

The final report will be a guidance document to TxDOT Engineers on procedures for evaluating and using FS in transportation applications.

1.2 ORGANIZATION

In Chapter 2, information available on FS in the literature has been reviewed and summarized. Applications for FS have been identified. In Chapter 3, the results of the survey undertaken during this study with the collaboration of the Texas Cast Metal Association (TCMA) are summarized and analyzed. Available FS in various TxDOT Districts has been quantified. By random sampling of FS across the State of Texas, engineering and environmental properties of FS available in Texas have been quantified. Designing flowable fills using the FS available in Texas, field study results from Brownwood, Texas and modified TxDOT Specification on flowable fills to include FS have been included in Chapter 4. Chapter 5 includes the design of cemented sand mixes using FS, field study results from Houston, Texas and modified TxDOT Specification on cemented sand. The findings and conclusions of this study are in Chapter 6. Additional information relevant to this project is placed in the Appendices.

CHAPTER 2. LITERATURE REVIEW

Foundry sand (FS) is a sand mixture consisting of a of clean, mainly uniformly sized, high-quality sand (Table 2.1) to which clay, or chemical binder, combustible additives, and water are added to produce a bond. Foundry sand is being used in the casting industries as follows: (1) molds that form the outside of the casting and (2) core that form the internal shapes and cavities within the casting. Most sand cast molds for ferrous castings are of the clay-bonded sand (green sand). Green sand consists mainly of high-quality silica sand, which has a fusion point of about 1,700°C, clays, water and additives. Clays used in foundries, regardless of type, are hydrous alumina silicates, and their properties provide cohesion and plasticity in the green state and high strength when dried. Chemically bonded sand cast systems are also used for cores and for molds for both ferrous and nonferrous castings.

2.1 FOUNDRY SAND

2.1.1 SAND

Sand is used as the molding material for many reasons. Thermal resistance and convenience to obtain it makes sand as a main material of mold making (Parkes, 1971). The sand is responsible for the thermal properties and the surface finish of the casting (Parkes, 1971). The mechanical behaviors of sands are notably influenced by their physical properties (Miura et al. 1998). The physical properties of sand can be classified into primary properties such as density, hardness, shape, and size of grains and secondary properties such as void ratio, moisture content, crushability and angle of repose (Miura et al, 1998). Some of the types of sands used in the molding processes with their properties are summarized in Table 2.1.

2.1.2 BINDER

The most common binder used in sand is clay (green sand), but chemical polymers may also be used. Regardless of the binder used, it must provide sufficient strength and plasticity as well as the ability to collapse after shakeout. Collapsibility is required for

Table 2.1 Types of Sands Used in Foundries (Report of AFS Molding and Core Aggregate Committee).

	Silica	Olivine	Chromite	Zircon	Zircon/Aluminum Silicate	StauroliteE
Origin	U.S.A	U.S.A(Washington N.Carolina)	Republic Of South Africa	U.S.A	U.S.A(Florida)	U.S.A(Florida)
Color	White-light brown	Greenish gray	Black	White -brown	Salt and pepper	Dark brown
Bulk density (lb/ft^3)	85-100	100-125	155-165	160-185	155-168	143-146
Specific gravity	2.2-2.6	3.2-3.6	4.3-4.5	4.4-4.7	3.2-4.0	3.1-3.8
Grain Shape	Angular/rounded	Angular	Angular	Rounded/angular	Rounded	Rounded
Fusion Point	2,600 - 3,200 F (1,427- 1,760 C)	2,800 - 3,200 F (1,538- 1,760 C)	3,200 - 3,600 F (1,760- 1,982 C)	3,700 - 4,000 F (2,038- 2204 C)	3,300 - 3,600 F (1,815- 1,982 C)	2,500 – 2,800 F (1,371- 1,538 C)
Chemical Reaction	Acid – neutral	Basic	Neutral-basic	Acid-neutral	Neutral	Neutral

foundries to reuse sand (Parkes, 1971). Clay binder may be present in proportions ranging from 2 to 50% by weight of sand (Heine et al. 1967). The typical range of clay content is 5 to 15%(by weight), and is determined by the type of clay necessary to obtain the desired properties (Hoyt, 1996). Bentonites are the most useful clays for foundry work and occur naturally in two forms - sodium or calcium bentonite (FOUNDRY, management and technology, December 1988). Sodium bentonite differs from calcium bentonite in that sodium cations are absorbed to satisfy the net negative charge on the mineral surface. Sodium bentonite exhibit greater swell and plasticity than calcium bentonite. The practical result in terms of the foundry industry is that sands bound by sodium bentonite have higher hot and dry strengths, as well as greater plasticity (Parkes, 1971). They are also more tolerant of water content deviations (Hoyt, 1996) and have greater resistance to thermal degradation (Heine et al. 1967).

Calcium bentonite sands have slightly higher green strength than sodium bentonite. Sands bound with either type of bentonite have higher strength and plasticity than those using kaolinite as the binder. The presence of clay binder has significant geotechnical consequences. The clay fraction may swell considerably when in contact with water, resulting in undesirable deformations of a pavement surface. Clay soils are also susceptive to frost damage. They typically undergo considerable strength loss during spring thaw. These problems will be exacerbated if sodium bentonite is present in the sand. Additionally, the presence of clay reduces the hydraulic conductivity, potentially resulting in poor drainage of a roadway structural fill or subgrade.

Alternative binders are also used in the casting process, primarily as the binder in the core sand. Alternative binders are typically organic compounds that are added as a liquid. The sand/liquid binder blend is placed into core molds and then subjected to elevated temperatures. The liquid organic binder is altered by the heat and converted into a solid that hardens the sand/binder blend (Heine et al. 1967).

2.1.3 ADDITIVES

Organic additives are used to impart the desired surface finish on the final product by favoring reduction over oxidation (Heine et al. 1967). Reduction prevents compounds in the molding sand from chemically combining with the metal thereby suppressing the formation of iron oxide ((Parkes, 1971). Formation of iron oxide provides adhesion between the molding sand and casting causing poor surface finish and shakeout. The additives used for oxidation suppression must contain hydrocarbons to function. The most popular of these is coal dust, commonly called "sea coal." It is finely ground coal blended in quantities ranging from 2-8% by weight (Heine et al. 1967). Some organic additives also contribute to plasticity and dry strength of sand. Numerous organic additives have been used in the metal casting industry and the selection of additives depends on the local availability and the specific characteristics of sand prevalent at individual foundries.

Other carbonaceous additives include asphalt, pitch, and fuel oil. A potentially significant result of the inclusion petroleum-based carbons is that they may "waterproof" the sand if used in excess, resulting in sand that resists the addition of water.

2.1.4 WATER

Water is added to sand to activate the binding properties of the clay binder. It is typically 2-7% (by weight) of the sand prior to contact with the molten metal (Hoyt, 1966a). Increasing the water content up to threshold water content will results in an increase in the dry and hot compressive strength. Above the threshold, a reduction in compressive strength occurs. Conversely, increasing the water content decreases the green strength regardless of water content (Parkes, 1971).

2.2 FOUNDRY SAND PROPERTIES

Since foundry sand will vary from foundry-to-foundry and state-to-state, it is important to develop a comprehensive database on their applications and relevant tests as summarized in Table 2.2. Number of applications for FS has been identified and most of the testing is limited to laboratory study. Based on the literature review, range of FS properties reported in the literature are summarized in Table.2.3.

Table 2.2 Some of the Applications and Related Testing of Foundry Sand

Location	Applications	Recommended Limit/Source /Composition	Study Lab	Study Field	Testing programs	Remarks	Reference
Canada	Pavement	Not available	√		Not available	1. The potential of WFS in transportation construction were summarized. 2. The limiting factors were discussed.	Emery (1992)
Milwaukee, WI	Concrete	Not available	√		Unit weight Strength	1. No pretreatment for green sand. 2. Specification was not provided. 3. Leaching was performed to evaluate the environmental concerns.	Naik (1994)
West Lafayette, IN	Embankment and subgrade applications	1. Up to 15% foundry sand was used. 2. Greensands were used.	√		Unit weight Bearing ratio Index properties Shear strength	1. No pretreatment for green sand. 2. Compared WFS with other aggregates. 3. Total quantity used was not available. 4. Leaching was performed to evaluate the environmental concerns.	Javed (1995)
Madison, WI	Highway construction	Not available	√		Unit weight Strength	1. No pretreatment for green sand. 2. Specification was not provided. 3. Leaching was performed to evaluate the environmental concerns.	Lovejoy (1996)
West Lafayette, IN	Flowable fill	3. A mixture of sand, clay, and organic matter.	√		Flow test Setting Permeability Strength	1. No pretreatment for green sand. 2. Compared WFS with other aggregates. 3. No specification was given. 4. Bioassay was performed.	Bhat (1996)
Auburn, IN	Highway embankment	1. Up to 35% foundry sand was used. 2. Greensand was from molding process. 3. A mixture of silica sand (85 - 90%), bentonite (4 - 10%) , and organic binder.	√	√	Index properties Particle size Specific gravity Compaction Permeability Shear test Bearing ratio	1. No pretreatment for green sand. 2. Field specification was provided. 3. Total quantity used was not available. 4. Cost analysis was provided.	Mast (1998)
Madison, WI	Hydraulic barrier	1. Up to 35% foundry sand was used. 2. Greensand was from gray-iron foundries. 3. A mixture of silica sand, bentonite, and organic binder	√	√	Index properties Compaction Permeability Free-thaw Desiccation	1. No pretreatment for green sand. 2. Quality assurance program was followed. 3. Total quantity used was not available.	Abichou et al (1998)
Remarks	Highway embankment and flowable fill were the most common applications	1. Green sand is the most common used. 2. Up to 35% foundry sand was used.	1. Most are laboratory studies. 2. Various engineering properties have been reported.			1. No pretreatment for foundry sand is needed. 2. Information regarding the specification of WFS in construction is limited. 3. Total quantity used was not available.	

Table 2.3. Summary of Physical and Mechanical Properties of Green Sand from Foundries.

PROPERTY		TEST STANDARD	FS	REFERENCE
Specific Gravity (Gs)		ASTM D 854	2.30 – 2.79	*1,*2,*3,*4,*7, *8
Atterberg Limit	LL(Liquid Limit)	ASTM D 4318	N.P – 30.70	*2, *3, *7
	PL(Plastic Limit)		N.P – 24.70	
	PI(Plastic Index		N.P – 25	
Particle Size Analysis	D_{10}, mm	ASTM D 422	0.007 - 0.10	*2, *3, *4
	D_{30}, mm		0.1 – 0.15	
	D_{50}, mm		0.18 – 0.30	
	D_{60}, mm		0.19 – 0.7	
	Cc		1.9 – 100	
	Cu		1.25 – 5.7	
	Percent passing #200 sieve (0.075mm)		0 – 40%	
Classification		USCS	SP-SM, SM, SP, SW-SM, SC, SC-SM, SP-SM	*2, *3, *7
		AASSTO	A-3, A-2-4, A-2-6	
Absorption (%)		ASTM C128	0.7 – 5.0	*4, *6, *7, *8
Roundness		Visual Chart Krumbein, 1941	0.55 – 0.69	*3
Hydraulic Conductivity, m/sec		ASTM D 5084	1.2×10^{-8}	*2, *4
Standard Proctor compaction test	$\gamma_{d\,max}$ ^{3}, lb/ft^3	ASTM D698	107 – 117	*2, *3, *4, *7
	w_{omc} ,%		9.6 – 27.1	*2, *3, *4, *7
Internal friction angle, degree (Direct shear and Triaxial test)		ASTM D3080, Triaxial(drained)	33°– 39°	*2, *4

*1: Javed and Lovell, 1994
*2: Patrick and David, 1998
*3: Kleven et al, 1998
*4: Eric and Alexander, 2000
*5: Naik et al, 1997
*6: Tikalsky et al, 2000
*7: Goodhue et al, 2001
*8: Naik et al, 2001

2.2.1 Physical and Mechanical Properties

2.2.1.1 Specific gravity (ASTM D 854)

One parameter that influence soil density and is often used as a method of comparison for engineering materials is specific gravity (G_s). Specific gravity test is performed according to ASTM D 854. The G_s values of new and used foundry sands are summarized in Tables 2.1 and 2.3 respectively. According to various studies the G_s of used FS ranged form 2.35 to 2.58 (Javed and Lovell, 1994); 2.46 to 2.53 (Patrick and David, 1998); 2.52 to 2.73 (Kleven et al, 1998); and 2.30 to 2.69 (Eric and Alexander, 2000). Generally the Gs for FS varied from 2.30 to 2.79 (Table 2.3).

2.2.1.1 Particle size distribution (ASTM D 421, D 422)

The particle size distribution of FS is very uniform, with approximately 85 to 95 percent of the material between 0.6 mm and 0.15 mm (No. 30 and No. 100 sieve sizes) and 5 to 12 percent of foundry sand can be expected to be smaller than 0.075 mm (Highway Research Center, User's guide). Particle size distribution of FS reported in the literature is shown in Fig. 2.1 and summarized in Table 2.3. The particle size distribution of FS is finer than ASTM C-33 which is the recommended sand for cement concrete.

2.2.1.2 Atterberg Limits (ASTM D 4318)

Fine-grained soils are generally tested to determine the Atterberg limits such as liquid limit, plastic limit and the Plasticity Index (PI). The typical Atterberg limit values of foundry sands are summarized in Table.2.3. According to various studies, the PI was in the range non-plastic to 8 (Kleven et al, 1998), 6 (Patrick and David, 1998), and 25 (Javed and Lovell, 1994) respectively. Hence the PI values of the foundry sand varied between N.P and 25.

2.2.1.3 Grain shape

The mechanical behavior of a granular material is governed by its structure and the effective stresses applied to it (Brown and Drummond, 2001). Factors that affect structure are the particle size and shape distributions and arrangement of grain contact (Brown and Drummond, 2001). Various attempt have been made to characterize particle shape. Some methods measure the overall shape or form, while others concentrate more on features such

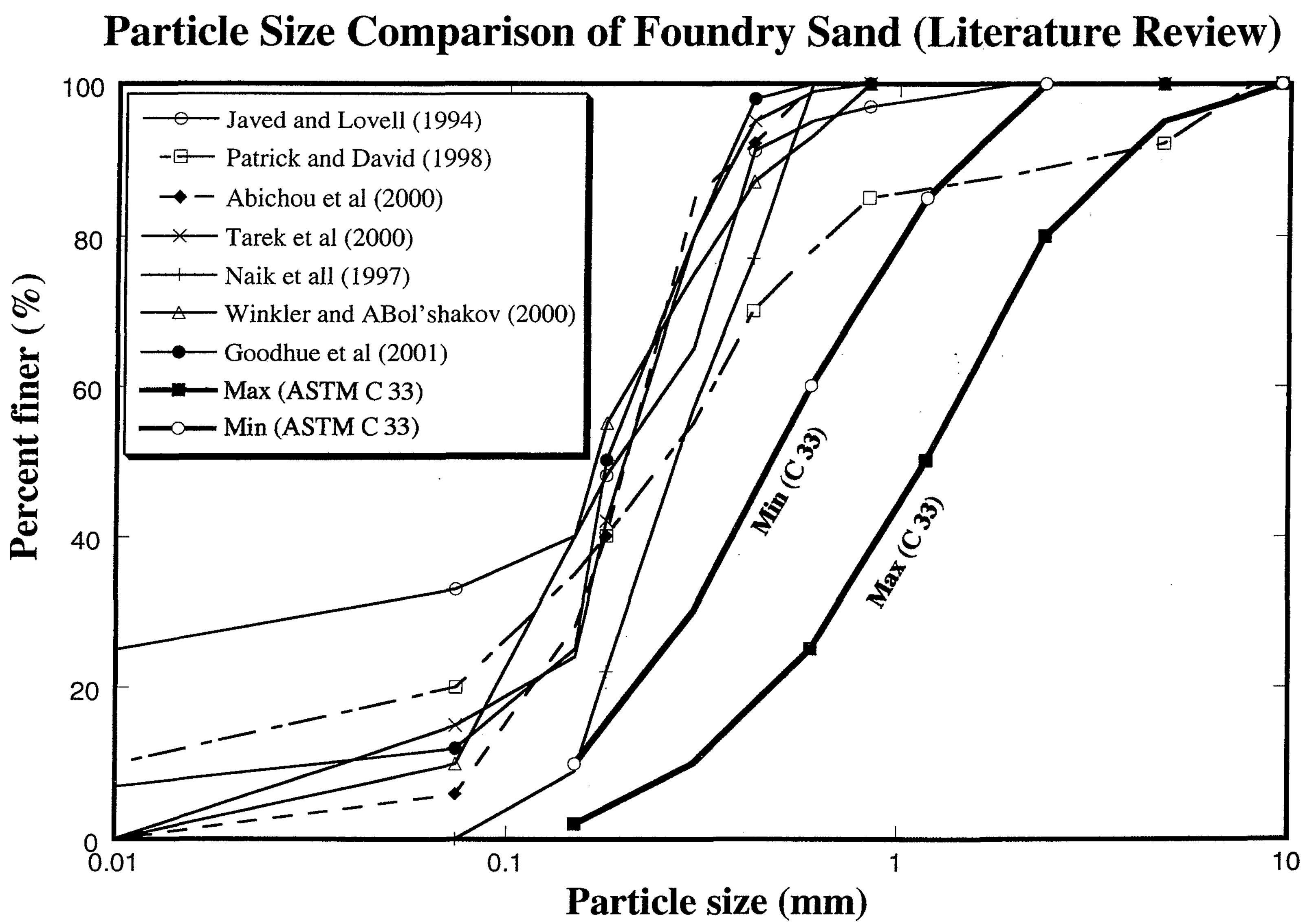


Figure 2.1 Particle Size Distributions of foundry sands are compared to the ASTM C 33 Sand used for Making Concrete.

as angularity versus roundness, and others on the still finer textural differences between shapes (Barrett, 1980). The grain shape of the sands used in the foundries varied from angular to rounded (Table 2.1).

2.2.1.4 Angle of repose

Terzaghi (1943) commented in his textbook that the angle of repose is a kind of angle of internal friction obtained in an extreme condition. Miura et al (1997) investigated the mechanism in a sand heap and indicated that the angle of repose corresponds to the angle of internal friction angle at the loosest state under a negligibly small confining pressure. The angle of reposes of general sands varied between 33 and 43 degrees (Miura et al. 1997).

2.2.1.5 Internal friction angle

Internal friction angle can be measured by triaxial compression test. For the FS, internal friction angle was in the range of 35 to 38 degrees and for unused foundry sand it was in the range of 33 to 39 degrees (Eric and Alexander, 2000; Patrick and David, 1998)

2.2.1.6 Hydraulic conductivity

Javed and Lovell (1994) used flexible wall permeameters to determine the hydraulic conductivity. For two FS specimens, hydraulic conductivity values were $2.8*10^{-5}$ cm/sec and $2.6*10^{-6}$ cm/s. Patrick and David (1998) obtained hydraulic conductivity values between the $1.4*10^{-4}$ cm/sec and $1.2*10^{-6}$ cm/sec. The hydraulic conductivity of FS measured by Eric and Alexander (2000) was $1.2*10^{-6}$ cm/sec.

Also the engineering properties of FS reported in the literature are summarized in Appendix A.

2.2.2 Environmental Properties

2.2.2.1 Loss on ignition (LOI)

FS is composed of silica sand, coated with a thin film of burnt carbon, residual binder such as bentonite, sea coal, and resin and dust. AFS (AFS, 1991) performed the x-ray fluorescence test and determined the chemical composition of FS and the loss on ignition (LOI) to vary between 0.45 and 9.5%.

2.2.2.2 Leaching properties

The environmental stability of FS has been studied by a number of investigations (Zirschky and Poznar, 1988; Ham et al, 1993; Tikalsky et al, 1998; Eric and Alexander, 2000). Tests have been conducted to determine the extent of metal and organic residues in foundry sand and some of the findings are summarized in Table 2.4. Green sand appears to be of very low organic compound leaching potential compared to the chemically boned sand. This result seems reasonable if one recognizes that mineral green sand systems would leach little organic matter (Eric and Alexander, 2000). Ham et al (1993) studied the potential and extent of ground water contamination by organic contaminants arising from FS using the TCLP. Leachates were analyzed by GC-MS (mass spectroscopic detection) for qualitative analysis and by GC-FID (frame ionization detection) for quantitative analysis. Laboratory results indicate that a wide variety of organic compounds were present in the FS leachates and that most are present at low concentrations. No samples produced concentrations above the regulatory toxicity limits. Based on the literature review it can be concluded that contaminants such as phenols, PAH and metals are of concern and the TCLP leaching and toxicity tests are the two most popular tests to evaluate FS.

Additional information on the environmental properties of FS are summarized in Appendix A.

2.3 FOUNDRY SAND APPLICATIONS

Generally, foundry sand from collapsed molds or cores is reclaimed and reused in the casting process several times. After repeated use, the sand is no longer able to maintain its desired properties during metal pouring. At that time, a portion of the sand is mixed with new materials to store its desire properties and rest of the sand is disposed as solid waste (foundry sand (FS)). Hence FS is available for beneficial use outside the foundry, in most cases replacing other conventional construction sands or granular materials. Numerous application

Table 2.4 Some of the Environmental Properties of Foundry Sands (FS)

Location	Environmental Concerns	Evaluations	Regulations	Remarks	Reference
Tuscaloosa, AL	Cu, Pb, and Zn	TCLP	U. S. EPA	1. Evaluated the hazard characteristics of foundry sand. 2. Recovering heavy metals from WFS was investigated.	Warren (1990)
Germany	PAHs	Toxicity tests	Germany Federal drinking water act	1. The concerns of disposing and using waste foundry sand are discussed. 2. Regeneration of FS was proposed.	Lahl (1992)
Ohio	Not available	Not available	Ohio EPA	1. Used foundry sand in composting. 2. Cost analysis was available.	Jing (1993)
West Lafayette, IN	Iron	Leaching tests	U. S. EPA	1. Greensand was used. 2. No pretreatment. 3. Leaching test was performed.	Javed (1995)
Kansas	Phenolic compounds	Leaching tests	U. S. EPA	1. Used cementitious materials to stabilize phenolics in waste foundry sands. 2. Leaching was performed.	Reddi (1996)
West Lafayette, IN	Not available	Bioassay test	Not available	1. Green sand was used. 2. No pretreatment. 3. Microtox test was performed.	Bhat (1996)
West Lafayette, IN	Organic and inorganic	Bioassay test	Not available	1. Green sand was used. 2. No pretreatment. 3. Microtox test was performed. 4. Cost analysis was available.	Fox (1997)
Remarks	1. Contaminants such as phenols, PAHs, and heavy metals are of concern. 2. Leaching and toxicity tests are the two most commonly used test to evaluated FS.		1. EPA's TCLP tests was used for leaching studies.	1. The leaching of toxic constituents from FS may be a concern. 2. Precautions must be taken in using FS.	

projects utilizing foundry sand has been documented in the literature (Abichou et al. 1999; Foundry Industry Recycling Starts Today (FIRST) web site). The types of applications using FS are summarized as follows;

(1) Structural/base/sub-base: Includes all the projects where FS has been beneficially used as structural fills, embankment materials, granular backfills, roadway sub-base and road way base materials (Mast and Fox, 1998). Of the 82 case studies documented by Abichou et al. (1999), 40% of the cases represented this application (Fig. 2.2).

(2) Asphalt concrete: Projects where FS has been used in the production of asphaltic concrete and bituminous concrete. Of the 82 case studies documented by Abichou et al. (1999), 22% of the cases represented this application (Fig. 2.2).

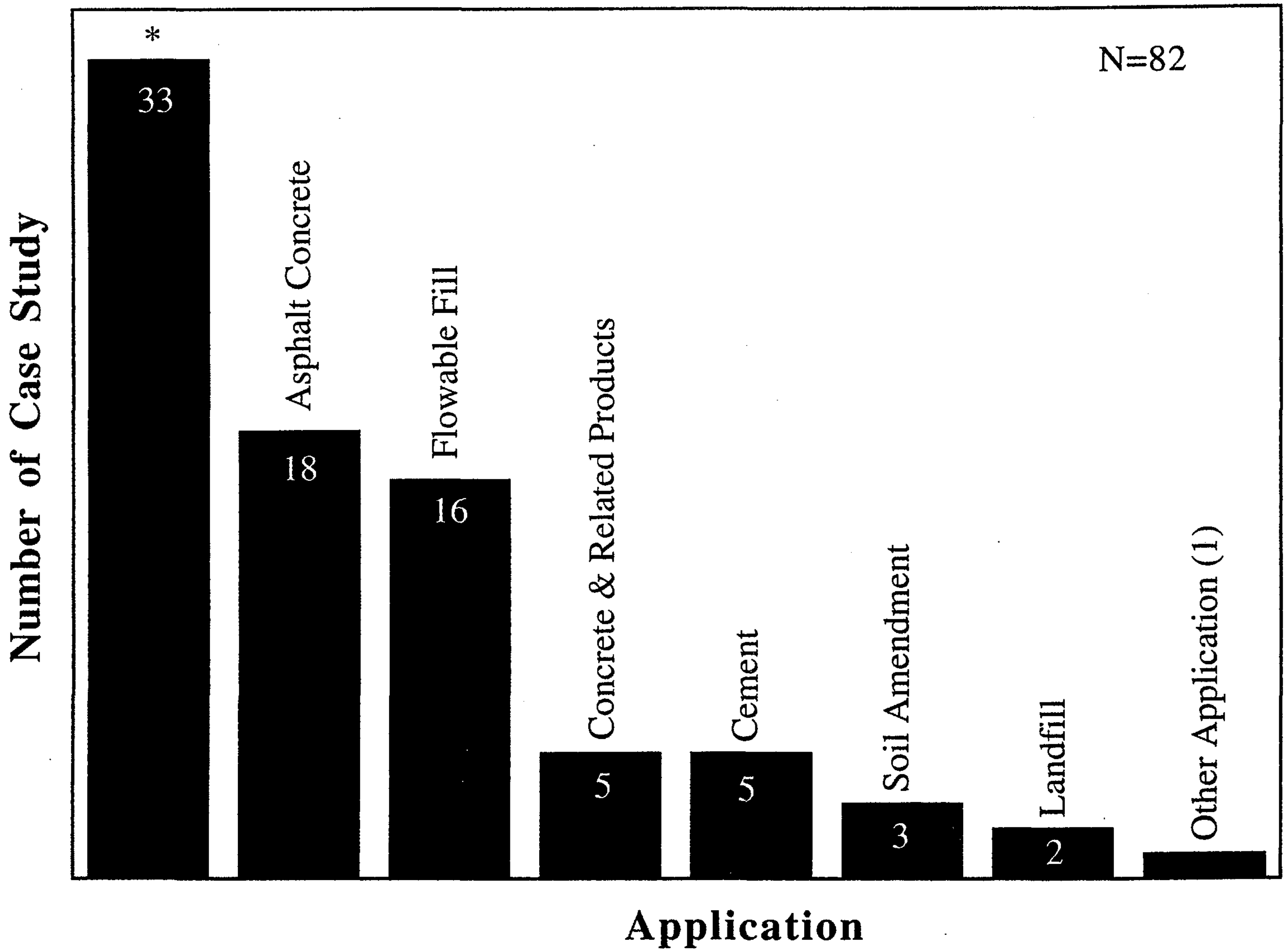
(3) Flowable fill : Projects where FS has been used in the production of controlled low strength materials (also known as flowable fills) (Tikalsky et al.1998; Naik et al. 1997; Vipulanandan et al. 2000; Naik et al. 2001). Of the 82 case studies documented by Abichou et al. (1999), 20% of the cases represented this application.

(4) Concrete and related products : projects where foundry by-products have been used in the production of concrete bricks, pre-cast concrete such as blocks, and in the construction of concrete pavements (Naik et al, 1994; Naik et al 1996). Of the 82 case studies documented by Abichou et al. (1999), 6% of the cases represented this application.

(5) Portland cement: Projects where foundry by-products have been used in the production of Portland cement amounted to 6% of the cases reported by Abichou et al. (1999).

(6) Soil Amendment: Projects where foundry by-products have been used in agricultural applications amounted to 4% of the cases reported by Abichou et al. (1999).

(7) Landfill liners: Projects where foundry by-products have been used in landfill liner or cover construction amounted to 2% of the cases reported by Abichou et al. (1999). There



* Structure/Base/Sub-Base Material

Figure 2.2 Distribution of Various Applications Using Foundry Sand (Abichou, 1999).

is growing interest in using FS in liner applications (Abichou etal. 2000, and Goodhve et al. 2001)

A number of application projects on foundry by-product utilization are also listed on the website- Foundry Industry Recycling Starts Today (FIRST)

2.4 STATE DOT SPECIFICATIONS

The use of flowable fills in transportation projects is gaining popularity, and a few state DOTs have developed or are developing specifications for flowable fills.

Iowa DOT: The Iowa Department of Transportation (IDOT) is a leader in the use of flowable fills. IDOT specifications require that the sand be fine sand with a maximum of 10% fines content, the cement content not to exceed 65 kg per m^3 (108 Lbs. per cubic yd), and the total amount of cementitious materials not to exceed 327 kg per m3 (545 Lbs. per cyd). IDOT also recommends the following mix for flowable fills containing foundry sand:

- 1560 kg/m^3 (2600 Lbs/ cubic yd) foundry sand
- 300 kg/m^3 (500 Lbs/ cubic yd) fly ash
- 60 kg/m^3 (100 Lbs/ cubic yd) cement
- 1400 L/m^3 (281 Gal/ cubic yd) water

Penn DOT: Pennsylvania has developed extensive specifications for flowable backfills. The specifications were developed for four types of flowable fills but only two Types of flowable fill had FS (Type B & C). TypeB-flowable fill is recommend where future excavation is desirable. It is typically used as backfill for utility trenches, pipe trenches, bridge abutments, and around box or arch culverts. Type C flowable fills are used when future excavation is not anticipated. It is typically used to replace unsuitable soils below foundations and to fill abandoned conduits, tunnels, and mines. PennDOT specifications for Type B and Type C flowable fills are summarized in Table 2.5. Flowable fills mixes must meet the density and strength requirements.

Wisconsin DOT: The Wisconsin DOT has also developed specifications for flowable fills. The specifications require that the mix have a flow of 225 mm (8 5/6 in.) per ASTM PS-28-95 and a 28-day compressive strength of 772 to 1517 kPa (112 to 220 psi). The specification

Table 2.5 PennDOT Specifications for Types B & C Flowable Fill

Property/Component	Type B	Type C	ASTM
Cement (lbs/cyd, kg/m3)	50/30	150-200/90-120	-----------
Fly ash (lbs/cyd, kg/m)	300/180	300/180	-----------
Fine Aggregate (lbs/cyd, kg/m3)	2600/1560	2600/1560	-----------
Slump (in/cm)	3/7.6 to 7/17.8	3/7.6 to 7/17.8	ASTM PS 28-95
Density (pcf/kN/m^3)	120/18.85 to 135/21	≥125/19.64	-----------
3-day Compressive Strength (psi/kPa)	25/172	300/2069	ASTM D 4832
28-day Compressive Strength (psi/kPa)	50/344 to 125/862	≥2400/16550	ASTM D 4832

allows the use of natural sand, natural gravel, produced sand, foundry sand, fly ash, Portland cement, and other broken or fragmented mineral materials.

Ohio DOT: The Ohio DOT specifications refer to flowable fills as low strength mortar backfills. They recommend the following mix design:

Table 2.6 Ohio DOT Specifications for Types I and II Flowable Fill

Component	Type I	Type II
Cement (Lbs/cyd, kg/m^3	50/30	100/59
Fly Ash (Lbs/cydk/m^3)	250/148	0
Sand (lbs/cyd, kg/m)	2910/1726	2420/1436
Water (Lbs/cyd, kg/m^3)	500/297	210/125 to 300/178

The Ohio specifications specifically mention the possibility of using foundry sands and require the development of alternative mixes to meet the strength and flowability criteria. These specifications also provide detailed information about mixing and placement of flowable fills.

Although other states require mix designs similar to the above specifications, they do not specifically refer to the use of FS as a portion or a full replacement of the fine aggregate in flowable fills. Specifications on other applications for FS are not available.

2.5 SUMMARY

Even though many states have developed beneficial reuse regulations for FS, large quantities are still being land filled throughout the U.S. However use of FS is increasing in the construction and transportation areas. Based on the literature review following conclusion can be advanced:

(1) Some of the most popular applications for FS are in roadway sub-base, embankment, asphalt concrete and flowable fill. Also a number of other applications have been identified for using FS. FS has not been used in cemented sand.

(2) FS particle size distribution was finer than ASTM C-33 sand used in concrete. The specific gravity of FS varied from 2.3 to 2.79. The plasticity index (PI) for FS varied from non-plastic to 25%. Based on USCS classification, the FS have been classified as SP, SM, SC and combinations in-between.

(3) TCLP and toxicity tests are the two most popular tests used to evaluate the leaching characteristics of the FS. The loss on ignition for FS varied from 0.45 to 9.5.

(4) Few state DOTs have specifications for using FS in folwable fill mixes.

Chapter 3. FOUNDRY SAND IN TEXAS

Key foundry states are California, Illinois, Indiana, Iowa, Michigan, Minnesota, Louisiana, Ohio, Pennsylvania, Texas and Wisconsin [Abichou et al. 1998; Vipulanandan, 1998]. The bulk of the FS is non-hazardous and is currently disposed in landfills costing between $20 to $40 per ton [Smith, 1991; Vipulanandan, 1998]. The annual generation of FS in Indiana was about 450,000 tons [Mast et al. 1998] and in the U.S. was estimated to be about 15 million tons [Ezra Kotzin (Technical Expert, American Foundrymen's Society (AFS) Headquarters, IL), Personal communication]. Since no such information was available on the foundry sand in Texas it was necessary to conduct a survey during this study,

In order to determine the quality of the foundry sand (FS) in Texas, it was necessary to determine the engineering and environmental properties of foundry sands available in Texas. Hence eleven samples (FS 1 through FS 11) were collected from around the State of Texas for limited laboratory testing. A QA/QC plan was developed for foundry sand testing (Appendix B). It was also necessary to verify if the foundry sand selected for field testing met the TxDOT Specification DMS 1100 for "Non-hazardous Recyclable Materials (NRMs)". Hence, a testing program was undertaken to characterize the geotechnical properties of the foundry sands and determine its leaching characteristics using the EPA and TNRCC testing methods. Another reason for the testing the Texas foundry sand is to show the amount of tests involved in qualifying the FS for use in TxDOT applications.

3.1. SURVEY AND RESULTS

A survey was undertaken with the participation of the Texas Cast Metal Association (TCMA). Sample of the survey sheet is in Appendix A which was mailed to all the members of the TCMA and other known foundries around the State of Texas. The TCMA contact for this survey was Mr. Mark Shelton. The purpose of the survey was to collect information on the following:

(1) Types of metal foundries (steel, iron, stainless steel, aluminum, brass/bronze)

(2) Types of molding sand processes (green sand, chemically bonded sand)

(3) Annual production of foundry sand in tons-per-year ?

(4) Amount of foundry sand in stock pile available for TxDOT project ?

(5) What percentage of foundry sand produced annually will be available for TxDOT projects ?

(6) Location where are the foundry sand is available ?

Total of 23 foundries responded to the survey and the distribution based on number of employees (reflect the size of the foundry) is shown in Fig. 3. 1. According to TCMA, 4 of the 5 foundries with more than 500 employees, considered to be the largest foundries in Texas, responded to the survey. Considered to be medium in size with 100 to 500 employees, 11 foundries responded to the survey. The rest of the respondents had less than 100 employees.

The foundries using only steel or iron (ferrous) in their production was 65% with 13% of the foundries use steel and other metals. Non-ferrous foundries was 22% of the respondents (Fig. 3.2). Green sand was produced by 30% of the ferrous foundries while the other 57% of the foundries produced both green and chemically bonded sands. The results of the survey are summarized in Tables 3.1 and 3.2. Over 93,000 tons of foundry sand is produced in Texas annually in 13 TxDOT Districts. Of this amount, over 60,000 tons (green sand and chemically stabilized sand) are available for use by TxDOT. Survey also indicated that ferrous foundries were producing over 42,000 tons of green sand annually. The largest quantity of foundry sand is produced in Lufkin District followed by the Dallas District. The distribution of foundry sand county by county in Texas is given in Fig. 3.3. Currently over 3.3 million tons of foundry sand is available in stock piles mainly in the Dallas and Houston TxDOT Districts (Table 3.2).

3.2. ENGINEERING PROPERTIES

Foundry sand samples were collected from many parts of Texas for this investigation. Total of eleven samples were collected and tagged from FS-1 through FS-11. Only FS-1 was unused sand and the properties was used for comparison with other foundry sands. Very detailed analyses was done on FS-9 since it was selected for field demonstration in the Brownwood District. Since FS-9 sand was received in two batches the sand was tagged as FS-9a and FS-9b. The foundry sands were black in color and had no organic smell with varying amount of moisture contents .

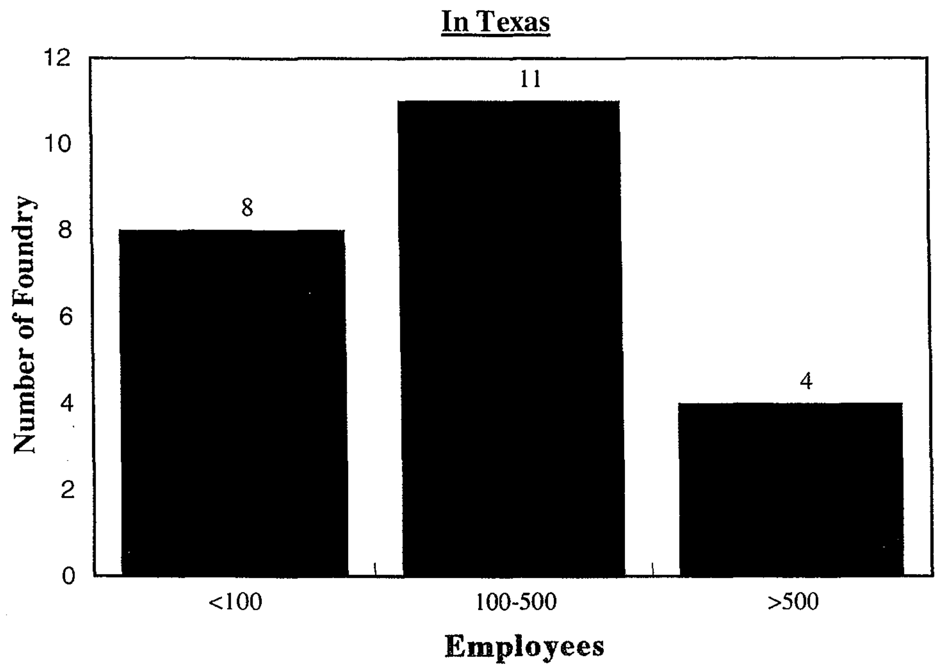


Figure 3.1. Distribution of Respondents to the Foundry Survey Based on Number of Employees.

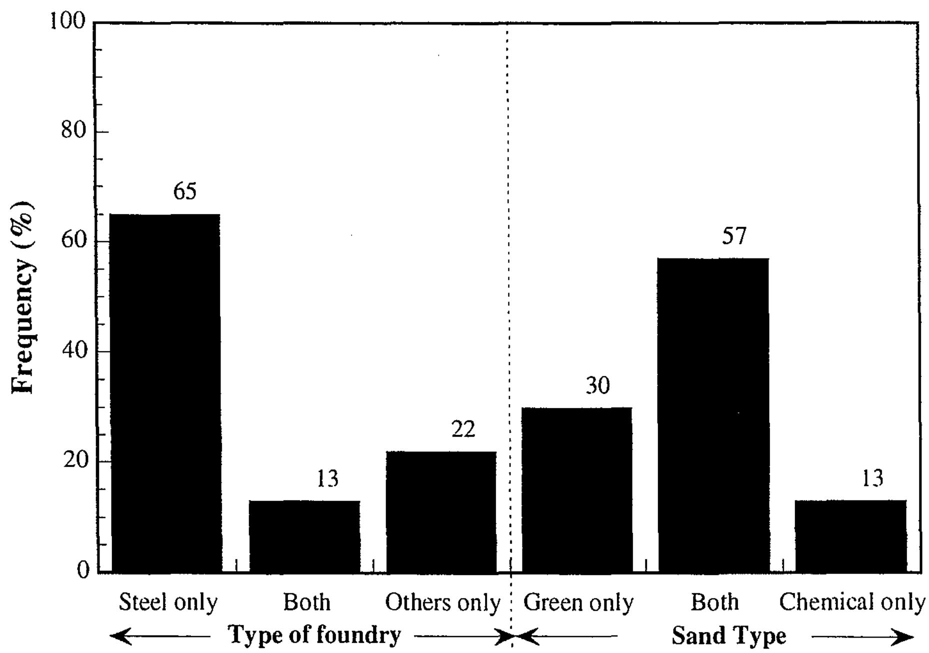


Figure 3.2. Distribution of Type of Foundry and Type of Sand Available Texas.

Table 3.1. Summary of Foundry Sand Survey in Texas

No	Name	Location (County)	TxDOT District	Type of Foundry		Sand Type		Production (ton/year)		Available for TxDOT (stock pile)			Remarks
				Steel/ Iron	Others	Green (GS)	Chemical (CBS)	Total	% Avail	Yes	No	Amount (tons)	
1	xxxxxx	Dallas	DAL	X		X		14,000	100	X		69,900	All GS
2	xxxxxx	Jeffferson	BMT	X		X	X	520	100		X	0	No details on GS
3	xxxxxx	Camp	ATL	X			X	1,200	100	X		20	All CBS
4	xxxxxx	Tarrent	FTW	X			X	?	90	X		320	All CBS
5	xxxxxx	Cooke	WFS	X		X	X	4,200	70		X	0	No details on GS
6	xxxxxx	Grayson	PAR	X		X	X	6,000	?		X	0	No details on GS
7	xxxxxx	Harris	HOU	X			X	5,400	10		X	0	All CBS
8	xxxxxx	Harris	HOU	X		X	X	200	100	X		Yes	No details on GS
9	xxxxxx	Lubbock	LUB	X	X	X		2,000	100	X		50	All GS
10	xxxxxx	Gregg	TYL	X		X	X	10,000	0		X	0	No details on GS
11	xxxxxx	Angelina	LUF	X		X		28,000	70		X	0	No details on GS
12	xxxxxx	Navarro	DAL	X		X	X	6,500	90	X		1,000	4,000 ton GS
13	xxxxxx	Gregg	TYL		X	X		40	90		X	0	Non-ferrous Metal
14	xxxxxx	Bowie	ATL	X	X	X	X	880	70		X	0	80 ton Green sand
15	xxxxxx	Harrison	ATL	X		X	X	0	0		X	0	Not interested

Table 3.1. Summary of Foundry Sand Survey in Texas (Continued)

No	Name	Location (County)	TxDOT District	Type of Foundry		Sand Type		Production (ton/year)		Available for TxDOT (stock pile)			Remarks
				Steel	Others	Green	Chemical	Total	% Avail	Yes	No	Amount (tons)	
16	xxxxxx	Tarrant	FTW		X	X	X	2,500	100		X	0	Non-ferrous metal
17	xxxxxx	Jefferson	BMT		X	X	X	50	50	X		0	Non-ferrous metal
18	xxxxxx	Harris	HOU	X	X	X	X	400	80	X		30	No details on GS
19	xxxxxx	Tarrant	FTW		X	X		100	80		X	0	Non-ferrous metal
20	xxxxxx	Brazos	BRY		X	X		45	100	X		30	Non-ferrous metal
21	xxxxxx	Dallas	DAL	X		X		80	?		X	0	Non-ferrous metal
22	xxxxxx	Eastland	BWD	X		X	X	4,900	100	X		4 - 10K	3,000 ton GS
23	xxxxxx	Amarillo	AMA	X		X	X	6,400	100		X	0	No details on GS
	Remarks	Total of 23 participation	Total of 13 Districts	65% are ferrous foundry (only)	22% are non-ferrous foundry	33% only produce Green sand	13% only produce chemically bonded sand	Total of 93,415 tons/ year	Total of 61,797 tons/ year available for TxDOT	43% had stock pile	57% had no stock pile	Total of more than 71,360 tons	More than 90,000 ton/year FS produced in Texas. Over 61,000 ton/year available. Over 42,000 tons/year GS from ferrous industry

Table 3.2: Distribution of Foundry Sand in TxDOT Districts and Potential Applications

No	District	Foundry Size			Annual Pro.	Stock Pile*	TxDOT Applications				Remarks##
		> 500	100-500	<100	(Tons/Year)	Tons	Flowable Fill	Embank-ment	Cemented Sand	Others	
1.	Amarillo		1		6,400	0	X				Flowable fill
2.	Atlanta		2	1	2,080	20	?	?	?	?	Not available
3.	Beaumont		1	1	570	-	X				Flowable fill
4.	Brownwood	1			4,900	4-10,000	X				Flowable Fill
5.	Bryan			1	45	30	?	?	?	?	Not available
6.	Dallas	1	1	1	20,580	>3,000,000	X			Fill mateial	Nuber of applications
7.	Fort Worth		2	1	2,500	320	X			sub base material	Nuber of applications
8.	Houston		1	2	6,000	330,000	X		X	Bond breaker	Nuber of applications
9.	Lubbock		1		2,000	50	X				Flowable fill
10.	Lufkin	1			28,000	-	?	?	?	?	Not available
11.	Paris		1		6,000	-	?	?	?	?	Not available
12.	Tyler	1		1	10,000	-	X				Flowable fill
13.	Wichita Falls		1		4,200	-	X				Flowable fill
	Remarks	4 out of 5 responded	Most responded	Most responded	Greater than 93,000 ton/year produced in 13 TxDOT districts	Over 3.3 million tons are available in stock piles	Most popular application	Not of interest yet	Popular in Houston district	Number of emerging applications	Over 3.3 million tons in stock pile. 93,000 tons produced yearly. Flowable fill is a popular application

* Data obtained for other material suppliers; ## Information from area engineers and material suppliers

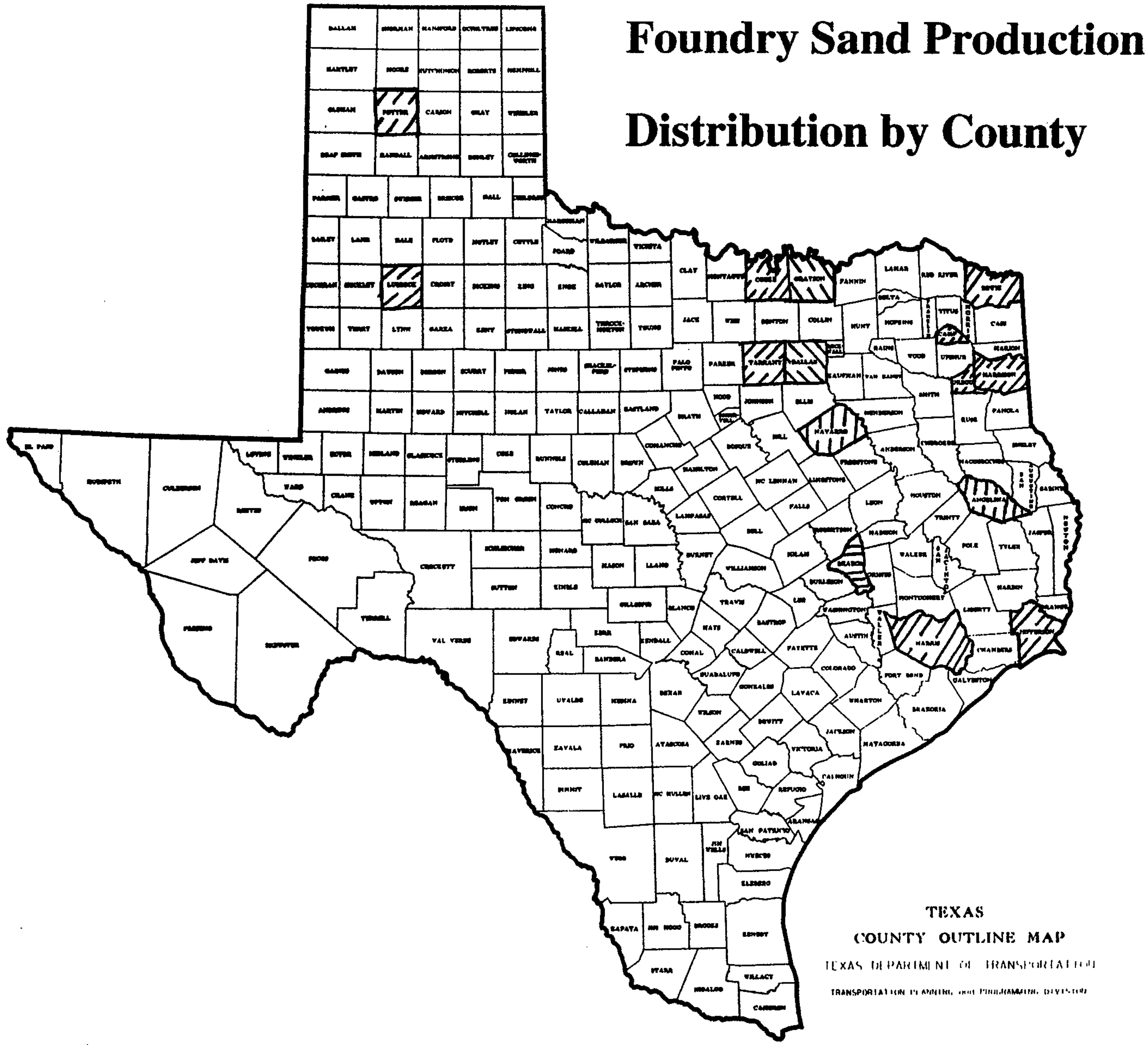


Figure 3.3. Foundry Sand (FS) Availability by Texas County.

(i) Specific Gravity

Tests were performed according to standard testing method (ASTM D854). The variation of specific gravity for various foundry sand samples are shown in Fig. 3.4. For FS-1, unused sand the specific gravity was 2.66. The specific gravity of the FS-2 through FS-11 sands varied from 2.4 to 2.68. This is within the range of values reported in the literature. Lowering of specific gravity of foundry sands is partly due to the change in phase of the sand due to the processing conditions during its service life.

(ii) Natural Moisture Content

Tests were performed according to standard testing method (ASTM D2216 and TxDoT Tex-103E). The variation of moisture content for various foundry sand samples are shown in Fig. 3.5. For FS-1, unused sand the specific gravity was 0.1%. The moisture content of the FS-2 through FS-11 sands varied from 0 to 5.5%. This is within the range of values reported in the literature.

(iii) Particle Size Distribution

Particle size distribution of the foundry sand samples are compared to the ASTM C 33 fine sand (recommended for cement concrete) in Fig. 3.6. Also the particle sizes are summarized in Table 3.3. The particle sizes for the foundry sand including FS-1 are finer than ASTM C33 sand and hence based on particle size they cannot be used as replacement for ASTM C33 sand in cement concrete. The percentage soil passing the sieve #200 varied from < 2% to more than 10%. The coefficient of uniformity (Cu) and coefficient of concavity (Cc) were in the range of 2.2 to 3.8 and 1.1 to 2.1 respectively. For ASTM C 33 sand the C_u was in the range of 4 to 5 and C_c was in the range of 1 to 1.1.

(iv) Index Properties

Most of the foundry sands are classified as non-plastic (NP). FS-8, FS-9, FS-10 and FS-11 had index properties. FS-8 with very fine particles had the highest liquid limit and plastic limit of 57 and 21 respectively. FS-9b had a liquid limit and plastic limit of 48 and 17 respectively.

(v) Soil Classification

Based on the index properties and particle size distribution most of the FS were classified as SP under USCS classification (Table 3.3). FS-8 was classified as CH and FS-9a and FS-9b was classified SC. Based on AASHTO most of the foundry sands were either A-3 or A-2-6 .

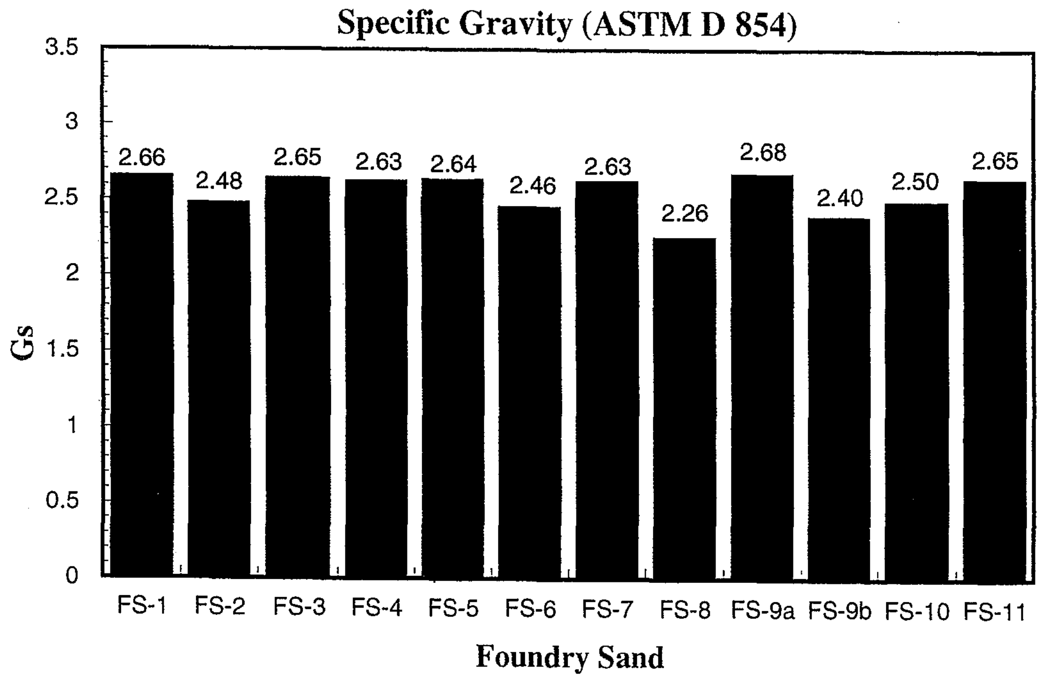


Figure 3.4. Distribution of Specific Gravity (G_S) of Texas Foundry Sands Tested During this Study.

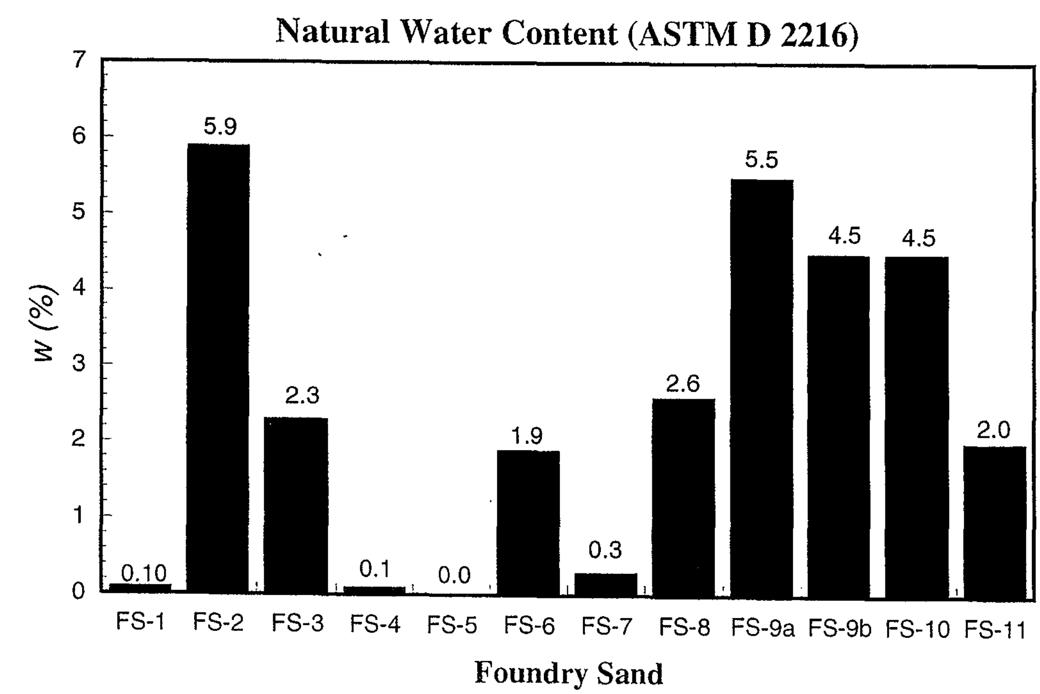


Figure 3.5. Distribution of Natural Moisture Content (w(%)) of Texas Foundry Sands Tested During this Study.

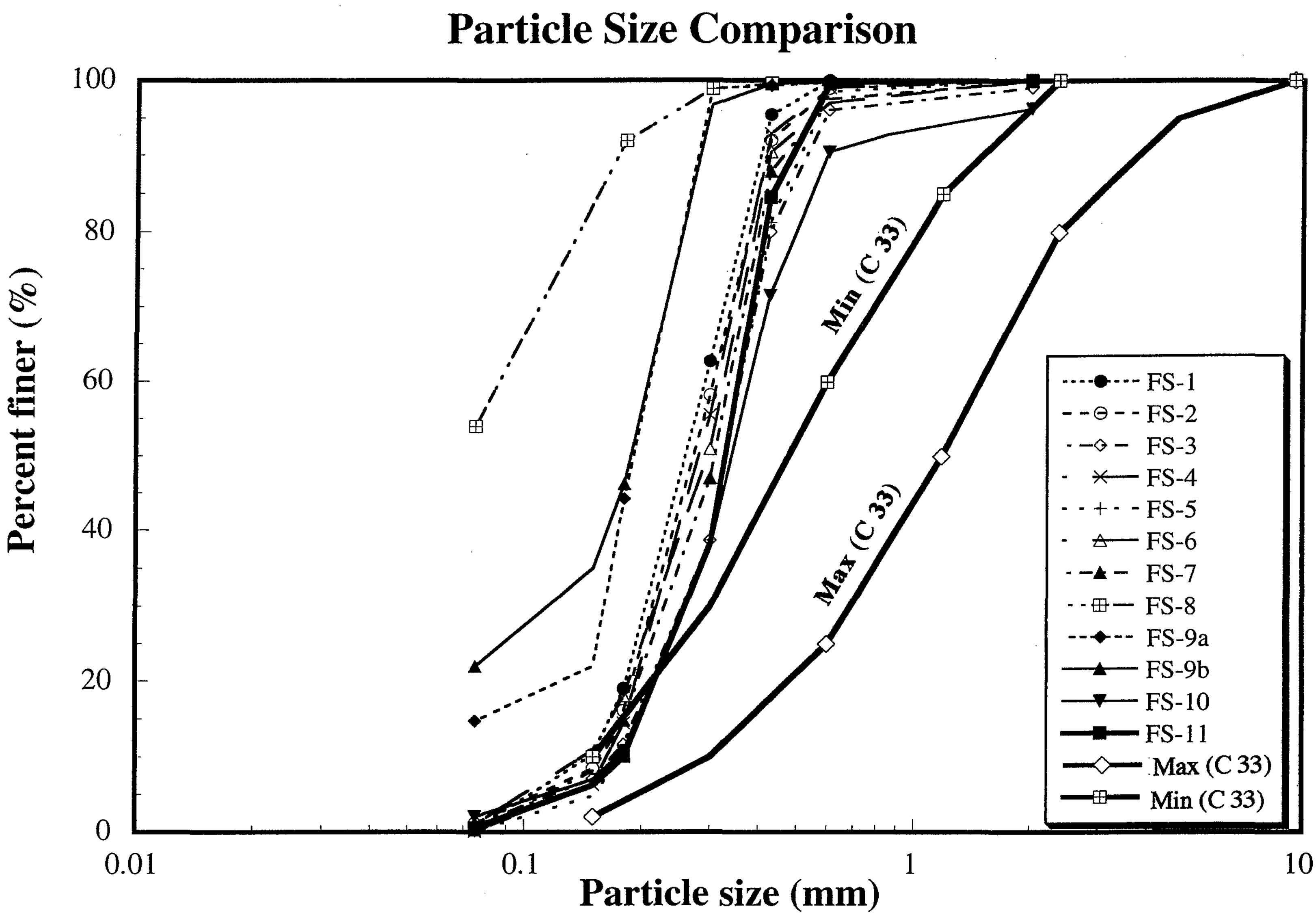


Figure 3.6. Particle Size Distribution of Texas Foundry Sands Tested During this Study.

Table 3.3. Summary of Engineering and Environmental Properties of Texas Foundry Sands

No	Initial Moisture (%)	P_{200} (%)	D_{10} (mm)	C_u	C_c	G_s	pH	L.O.I	LL	PL	PI	USCS
1*	0.1	0.4	0.147	1.98	0.99	2.66	7.1	0.01	NP	NP	NP	SP
2	5.9	1.1	0.156	1.96	0.95	2.48	7.1	6.73	NP	NP	NP	SP
3	2.3	0.9	0.169	2.13	1.10	2.65	8.3	0.47	NP	NP	NP	SP
4	0.1	0.1	0.163	1.92	0.94	2.63	8.7	1.5	NP	NP	NP	SP
5	0.0	0.1	0.177	2.01	1.04	2.64	7.9	1.91	NP	NP	NP	SP
6	1.9	1.0	0.141	2.30	1.03	2.46	8.0	6.93	NP	NP	NP	SP
7	0.3	0.3	0.158	2.12	0.99	2.63	9.5	0.8	NP	NP	NP	SP
8	2.6	54.0	-	-	-	2.26	10.0	31.8	56.8	21	35.7	CH
9a	5.5	14.0	0.04	5	3.2	2.68	9.2	0.5	31.2	16.7	14.5	SC
9b	4.5	22.0	0.015	14	4.6	2.40	9.4	-	48.0	17	31	SC
10	4.5	2.4	0.17	1.1	2.2	2.50	8.9	-	6.0	NP	-	SP
11	1.7	0.5	0.18	2	1.1	2.65	9.1	-	24.0	20.6	3.4	SP

* Unused foundry sand

3.3. ENVIRONMENTAL PROPERTIES

In order to use the Texas foundry sands to be selected for transportation applications, it is important to characterize its environmental properties and compare to the risk levels established by the TNRCC.

(i) **pH**: It was determined by using 30 g of sand in 150 ml of deionized water. (TxDOT Tex-128E). The water used in this study had a pH of 7.5. For FS-1, unused sand the pH was 7.1. pH of the foundry sands varied from 7 to 10.2. Results are summarized in Fig. 3.7. This is within the range of values reported in the literature.

(ii) **Loss on Ignition (LOI)**: (450°C for 4 hours).Tests were performed according to standard testing method (ASTM D2974). The variation of LOI for various foundry sand samples are shown in Fig.3.8. For FS-1, unused sand the LOI was 0.01%. Except FS-8, for all the other FS sands LOI varied from 0.5 to 7.0. This is within the range of values reported in the literature.

(iii) Leachability:

There are a number of leaching tests but it is important the select the most relevant test to evaluate the foundry sand. Both TCLP and TNRCC methods were used to first screen the foundry sand. After discussion with the Environmental Engineering Division of the TxDOT total analysis using the SW 846 methods were included in this study. The detailed investigation was limited to few foundry sands available in Texas.

(a) TCLP Analysis

In order to qualify the foundry sand for field application, leachability study was done in two stages. A QA/QC plan was developed to determine the leachability of total metals, total organics and total petroleum hydrocarbons (TPH) from the selected foundry sand (Appendix C). Initially TCLP and TNRCC tests were performed on selected FS and the results are summarized in Table 3.4. During the TCLP and TNRCC tests 27 metals were analyzed (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sn, Sr, Ti, V, Zn) and none of them exceeded the EPA and TNRCC limits for metals. TCLP results on Texas FS-1, FS-2, FS-3 and FS-9a are compared to FS from Wisconsin and Pennsylvania. Compared to Wisconsin and Pennsylvania FS sands, Texas FS sands had higher levels of Ca and Na but these are of no environmental concern.

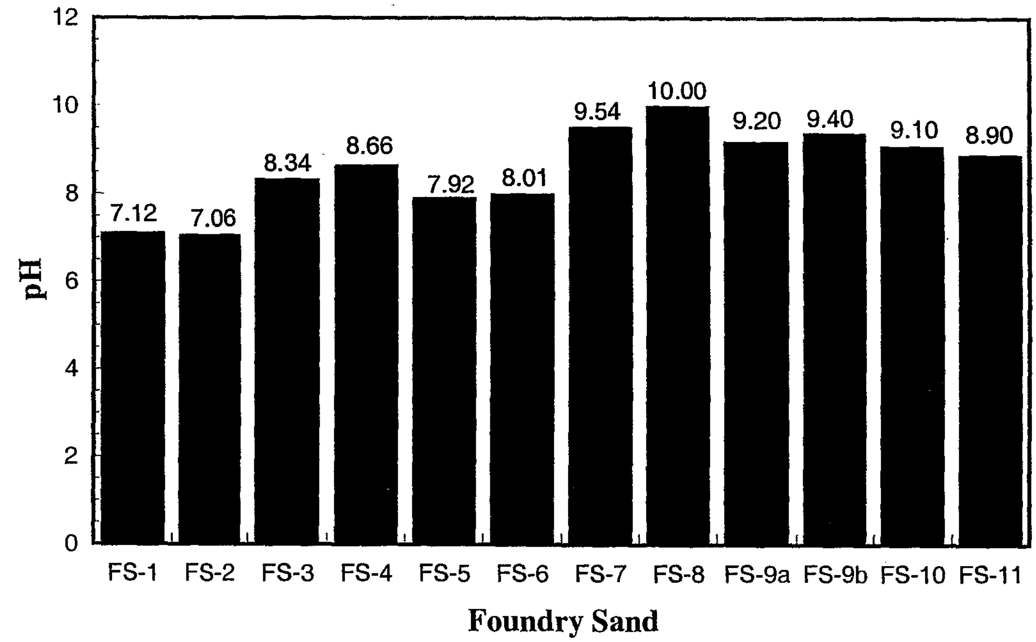


Figure 3.7. Distribution of pH of Texas Foundry Sands Tested During this Study.

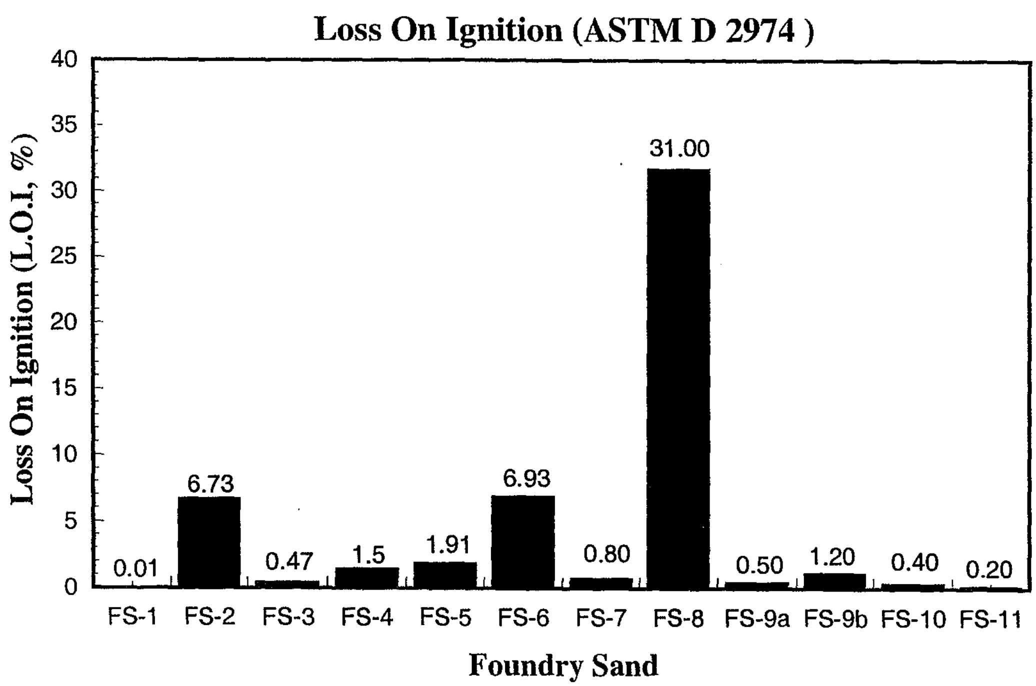


Figure 3.8. Distribution of Loss on Ignition (LOI) of Texas Foundry Sands Tested During this Study.

Table 3.4. Comparison of TCLP tests for Texas Foundry Sands with Wisconsin and Pennsylvania Foundry Sands.

Contaminant	TCLP Limit (mg/L)	Texas (mg/L)				Wisconsin (mg/L)			Pennsylvania (mg/L)
		FS-1	FS-2	FS-3	FS-9	FS-1	FS-2	FS-3	
Ag	5.0	<0.01	<0.01	<0.005	<0.005	ND	ND	ND	2.5
Al	-----	2.065	1.680	14.888	2.597	ND	ND	ND	5.0
As	5.0	<0.05	<0.05	<0.02	<0.02	<0.279	<0.279	<0.279	1.25
B	-----	10.47	10.10	12.820	13.979	0.103	0.381	0.157	-----
Ba	100.0	0.041	0.145	0.239	0.436	0.337	0.164	0.337	50.0
Be	0.007	<0.001	<0.001	0.0004	0.0022	ND	ND	ND	0.1
Ca	-----	8.345	33.69	76.063	34.809	ND	ND	ND	0.125
Cd	1.0	<0.005	<0.005	0.015	0.003	<0.010	<0.010	<0.010	-----
Co	-----	0.005	<0.005	0.020	<0.005	ND	ND	ND	-----
Cr	5.0	<0.005	<0.005	0.972	<0.005	<0.017	<0.017	<0.017	2.5
Cu	-----	ND	ND	0.281	0.004	0.164	0.220	0.166	32.5
Fe	-----	0.141	0.048	ND	ND	7.701	2.743	12.81	7.5
Hg	0.2	ND	ND	ND	ND	<0.014	0.309	<0.014	0.05
K	-----	1.170	4.925	<0.1	<0.1	4.195	1.364	6.946	-----
Mg	-----	0.830	3.127	26.616	47.506	ND	ND	ND	-----
Mn	-----	0.094	0.138	0.089	0.295	0.796	<0.014	0.795	1.25
Mo	-----	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	4.375
Na	-----	1502.0	1587.0	2150.2	2237.9	ND	ND	ND	-----
Ni	70	0.161	0.006	0.295	0.007	ND	ND	ND	2.5
P	-----	0.554	<0.5	0.355	0.212	ND	ND	ND	-----
Pb	5.0	0.103	<0.02	0.036	0.031	<0.111	<0.111	<0.111	1.25
S	-----	0.56	12.93	0.823	12.505	ND	ND	ND	-----
Sb	1.0	<0.05	<0.05	ND	ND	ND	ND	ND	0.15
Se	1.0	<0.1	<0.1	0.053	<0.05	<0.190	<0.190	<0.190	1.0
Si	-----	91.0	91.2	152.55	110.39	ND	ND	ND	-----
Sn	-----	<0.05	<0.05	<0.05	<0.05	ND	ND	ND	-----
Sr	-----	0.037	0.723	0.136	1.038	ND	ND	ND	-----
Ti	-----	<0.005	<0.005	0.023	<0.01	ND	ND	ND	-----
Tl	7.0	ND	ND	ND	ND	ND	ND	ND	0.0125
V	-----	<0.01	<0.01	<0.005	<0.005	ND	ND	ND	-----
Zn	-----	0.974	0.017	0.389	0.092	0.555	2.980	0.785	125.0

In addition to both TCLP and TNRCC tests total analyses tests were also performed on the sands. Results for FS-9 (Batch-2) sands are summarized in Table 3.5 (metals) and Table 3.6 (TPH). Based on the literature review, only Pb, Cr and Cu were measured in the total metal analysis. None of the metals exceeded the TNRCC RRS2 (Risk Reduction Standard No. 2, July 14, 1999) limit for soil. Note that only the results for Pb, Cr and Cu are summarized in Table 3.5 and more metals and other details are in Appendix C. Total organic and TPH analysis for FS-9 (Batch-2) are summarized in Table 3.6. From the GC analysis of the extracts (Fig. 3.9) no additional organic peaks were detected and the change in the peaks were negligible. Hence it can be concluded that there is no detectable amount of organics or petroleum hydrocarbons in the foundry sand.

(b) Total Analysis

In order to use the stockpile foundry sand (FS) in the Brownwood district for the TxDOT project additional tests were performed. Volatile organics (VOC), semi volatile organics (SVOC), total metals, mercury and TPH in the FS were determined using the standard test methods as outlined in the QA/QC Report dated (Appendix C). All the environmental test results apply to this stock pile of FS from which samples were obtained for analyses and compared to the TNRCC RSS2 risk levels.

(b.1) Results

Based on the analysis following can be concluded on the level of contamination in the foundry sand.

SVOC : Among the 16 SVOCs analysis, only fluoranthene and pyrene were detected in foundry sand samples. Both concentrations were below TNRCC GW-Res and GWP-Res standards. The rest of SVOCs were below the detection limit for each chemical.

VOC: All 19 VOCs chemicals analyzed were below the detection limit for each chemical. Thus, none was violated TNRCC GW-Res and GWP-Res standards.

Total Metal Analysis: Among the 27 ions analysis, only Al, P, and Pb over the TNRCC GW-Res standard. However, only P violated TNRCC GWP-Res standard. Among the ions, B, Ca, Fe, K, Li, Mg, Na, S, Si, Sr, and Ti are not regulated by TNRCC.

Table 3.5. Leachability of Metals from Total, TCLP and TNRCC Test for Texas Foundry Sand (FS-9a).

Ion	*TX RRS2 (mg/kg)*	*Total-1*[1] *(mg/kg)*	*Total-2 (mg/kg)*	*Total-3 (mg/kg)*	*TCLP*[2] *(mg/L)*	*TNRCC (mg/L)*
Cr	5300	0.925	0.000	0.000	0.0	0.0
		0.000	0.000	0.000	0.0	0.0
		0.000	0.000	0.000	0.0	0.0
Cu	1000	1.793	1.793	1.793	0.0	0.0
		1.793	1.793	1.793	0.0	0.0
		1.793	1.793	1.793	0.0	0.0
Pb	500	9.848	9.848	9.848	0.1	0.1
		9.848	0.000	0.000	0.1	0.1
		9.848	0.000	0.000	0.0	0.0

Note: 1. EPA Method 3050B (Acid Digestion of Sediments, Sludges, and Soils)
2. EPA Method 1311 (Toxicity Characteristic Leaching Procedure)

Table 3.6. Total Organic and Total Petroleum Hydrocarbon Analyses (EPA Method 3550B) for Texas Foundry Sand (FS-9a).

Sample	*Peak (min)*	*Area*	*Area*	*TPH (mg/kg)*
Methylene Chloride	4.6	40670016	41425100	Control
	10.8	706	724	
	35.1	31301	31301	
FS-9 (Batch-2)	4.6	38835712	38700455	Below detection limit
	10.8	650	667	
	35.1	28565	28127	
FS-9 (Batch-2)	4.6	390390348	39054432	Below detection limit
	10.8	638	612	
	35.1	17634	17909	

Mercury Analysis: Hg was not detected in the foundry sand samples. Thus, it did not violate TNRCC GW-Res and GWP-Res standard.

TPH Analysis: None were detected.

(b.2) Conclusions

Based on the experimental results and analyses of the test data the foundry sand (FS-9a) was selected for the field demonstration project in the Brownwood District.

3.4. ELECTRICAL PROPERTIES

When foundry sand is used as a backfill material it is important to determine it's specific resistivity to satisfy TxDOT requirements..

Specific Resistivity: Variation of electrical resistivity with moisture content for a selected foundry sand (FS-9a Batch-2) was measured and shown in Fig. 6. Changes in the specific resistivity with moisture content for the foundry sand is also compared to ASTM C 33 sand (clean sand). Foundry sand (Batch-2) had lower specific resistivity compared to the ASTM C 33 sand with the same moisture content. TxDOT requirement is that the sand must have a specific resistivity of over 3000 ohms-cm at the natural moisture content and hence the foundry sand (FS-9a: Batch-2) sand satisfied this requirement at its natural moisture content of 5.5%.

3.5 MSDS FOR FOUNDRY SAND

In order to streamline the quality of FS (for use in TxDOT projects), it is important to develop a MSDS with easy to understand instructions to be filled by the material supplier/owner. This will also help the foundries in supplying/marketing their materials to TxDOT .The acronym MSDS stands for the words Material Safety Data Sheets. MSDS is prepared in accordance with the OSHA Hazard Communication Standard 1910.1200. Current federal law requires every chemical supplier to provide the client with a MSDS sheet. Extensive search showed that there is no MSDS sheet available for FS. Hence in this study a MSDS sheet for FS has been developed (Appendix A) after reviewing MSDS from sand suppliers.

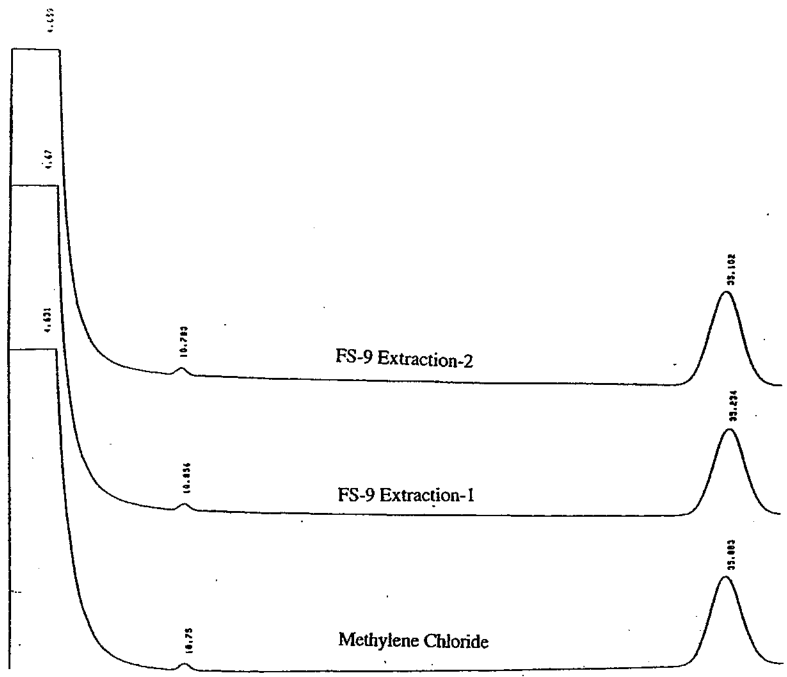


Figure 3.9. GC Analysis after Methylene Chlorides Extraction with and without Foundry Sand (FS-9a).

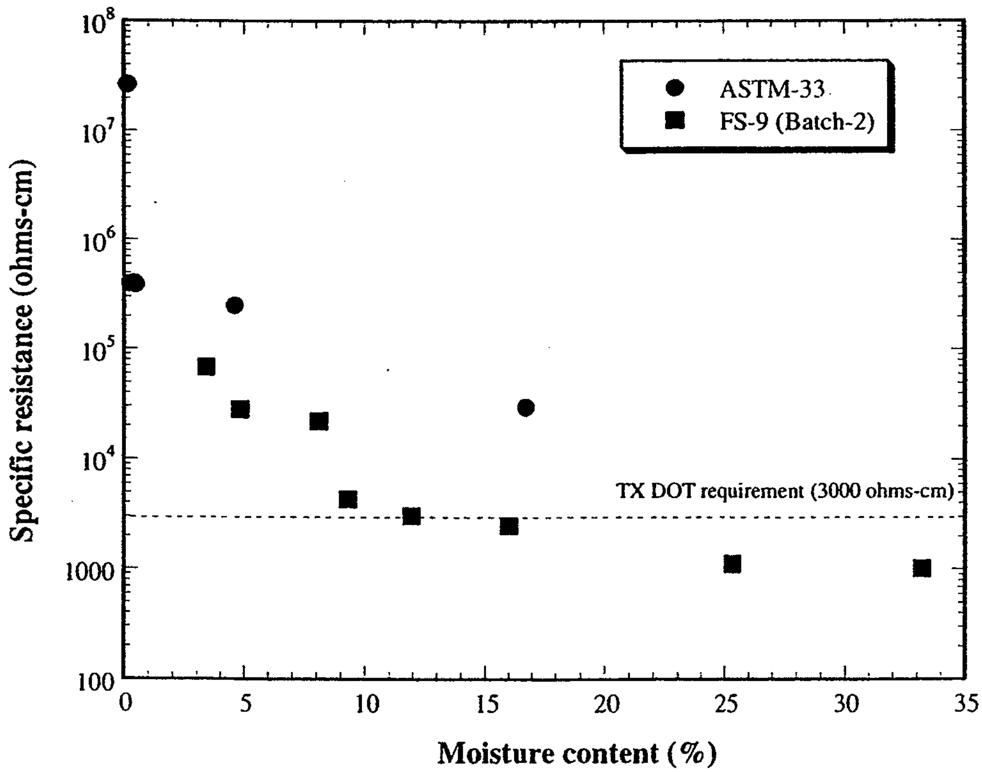


Figure 3.10. Variation of Specific Resistivity with Moisture Content for Foundry Sand (FS-9a) and ASTM C 33 Sand.

3.6. SPECIFICATION FOR FOUNDRY SAND (TxDOT)

When FS is used in construction/maintenance it must to meet the required engineering properties and environmental regulations based on the applications. Proposed specification for FS can become important in future designing of projects and in quality control.

X.1. Material: Foundry sand (ferrous) obtained by the Contractor must meet the requirements of the Texas Department of Transportation (TxDOT) and the Texas Natural Resources Conservation Commission (TNRCC) and satisfies the DMS-11000. The Contractor shall be responsible for securing all necessary permits that may be required for the transport and storage of foundry sand from the TNRCC and other federal, state, regional, county, or city agencies that may have jurisdiction over such transport and storage. Foundry sand used in cement stabilized backfill or flowable fill, when tested in accordance with the TxDOT test methods, will have suitable index, physical, electrical and mechanical properties. The contractor is responsible for furnishing the Engineer with documentation certifying that the proposed material complies with relevant 30 Texas Administrative Code (TAC) Section 335 subchapters. The source of foundry sand shall be approved by the Engineer prior to use.

Foundry sand: The spent sand obtained will be limited to ferrous industries. The molding sand process will be green sand. But chemically bonded sand will be considered if it satisfies all the mechanical, electrical and leaching test requirements and acceptable by the Engineer. It is required that the foundry sand be free of any metal debris.

3.7. SUMMARY

A survey was undertaken to determine the availability of foundry sand in Texas. The survey was undertaken with the help of the Texas Cast Metal Association. Also eleven foundry sand samples (FS-1 through FS-11) were obtained from around the State of Texas to determine the engineering and environmental properties of the foundry sands available in Texas. Based on the survey and testing following observations are advanced.

1. Based on the survey, over 93,000 tons of FS is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There is over 3.3 million tons of FS in stock piles in Texas.

2. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content

of the foundry sands varied from 0 to 5.5%. These values are within the range of values reported in the literature.

3. Most of the of Texas foundry sands tested were classified according to USCS as SP. Particle size of all the Texas FS tested were finer than ASTM C33 sand. The pH of the FS varied from 7 to 10.2. from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. These values are within the range of values reported in the literature.

4. The pH of the Texas foundry sands varied from 7 to 10.2. Except for one FS, all the others Texas FS had LOI in the range of o to 7%. The moisture content of the foundry sands varied from 0 to 5.5%. .

5. Few FS were selected for the TCLP and TNRCC tests. Analyses of 27 metals showed that all the tested FS sands passed the tests.

6. Leaching tests (total analysis) on a selected foundry sand (FS-9a) showed that based on SVOC analyses only flouranthene and pyrene were present and the concentrations were below TNRCC RRS2 limits. VOC analysis indicated that all the chemicals analyzed were below the detection limits. Total metal analyses indicated that Al, P and Pb were above the GW-Res limit but only P exceeded the TNRCC GWP-Res limit. No mercury or TPH were detected in the FS. The FS-9a tested can be characterized as non-hazardous material.

7. Specific resistance of selected FS sand at the natural moisture content was higher than 3000 ohm-cm which is specified by TxDOT as the minimum for backfill materials.

8. MSDS sheet and material specification for Texas foundry sand has been developed.

CHAPTER 4. DESIGNING OF FLOWABLE FILL

Flowable fill is a fast-developing, widely used Controlled Low Strength Material (CLSM). It is a flowable, cementitious material used primarily as a backfill in lieu of compacted fill. CLSM produced as flowable fill is a high-fluidity cementitious material that flows like a liquid, and self-levels without compacting (Naik and Singh, 1997). It is primarily used for nonstructural applications. In many situations, it provides an economical alternative to conventional compacted granular backfill materials. CLSM has been used extensively in many locations across the U.S. and Canada, extensively for backfilling trenches and open excavations adjacent to structural foundations (Eric and Alexander, 2000).

4.1 DATA ON FLOWABLE FILL WITH FOUNDRY SAND

One of the potential uses of foundry sand (FS) is in the production of controlled low strength material (CLSM). The CLSM with FS can be used for numerous applications, including as a backfill material for utility trenches, surrounding pipes and manholes, excavations in streets and around foundations; as a fill for abandoned tunnels, sewers, and other underground cavities, and for erosion control (Tikalsy et al. 2000).

Based on the literature review, information on 43 mixes with FS has been collected and analyzed to determine the mix designs and related properties.

(a) Composition

The major constituents of flowable fill are foundry sand, cement, fly ash, and water (Tikalsy et al, 2000). The amounts of constituents used in flowable fill mixes with foundry sand reported in the literature are summarized in the Table 4.1. Foundry sand is the major component of the flowable fill mixes.

(b) Water-to-Binder Ratio

The water-to-cement ratio varied from 3 to 15 with an average of 8.4 (Fig. 4.1). Water-to-binder (cement + fly ash) ratio varied from 0.4 to 8.9 with an average of 1.4. The variation of water-to-cement and water to binder ratios shown are in Fig. 4.1 and

Fig. 4.2 respectively. The results are also summarized in Table 4.2. Water-to-cement ratio varied from 7 to 9 for 45% of the mixes used. The water-to-cement ratio varied from 10 to 11 for 18% of the mixes. For 25% mixes water-to-binder ratio varied from 1 to 2 and 23% mixes water-to-binder ratio varied from 0.6 to 0.7 (Fig. 4.2).

Table 4.1 Flowable fill mixture proportions from 43 mixes with FS

Material	Range (lb/yard^3)
Cement	50 - 118
Fly ash	0 - 1519
Foundry sand	612 - 2555
Water	430 - 950

Table 4.2 Water-to-binder ratio for foundry sand flowable fill

43 Mixes	Water-to-Cement	Water-to-Binder
Range	3 - 15.0	0.4 - 8.9
Average	8.4	1.4
Mode Frequency	7 - 9	1 - 2

(c) Unit Weight

The unit weights of the mixes with foundry sand varied between 97 to 127 pcf (1555 to 2036 kg/m^3) (Fig. 4.3).

(d) Compressive Strength

The 28-day compressive strength of mixes with FS varied from 40 to 520 psi. The average strength was 104 psi. The data showed that 72% of the mixes had compressive

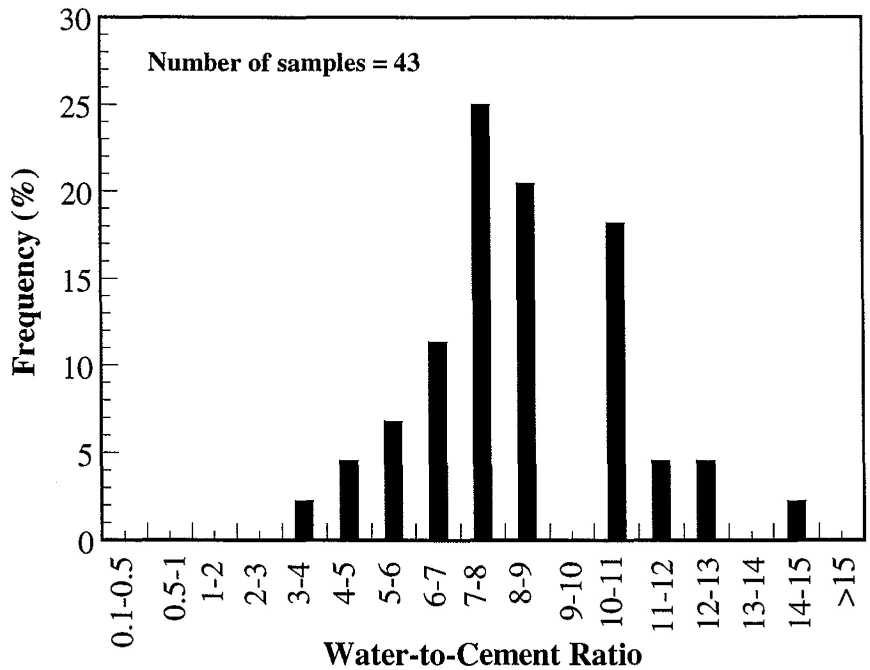


Figure 4.1 Variation of water-to-cement ratio for flowable fill with FS (Literature review)

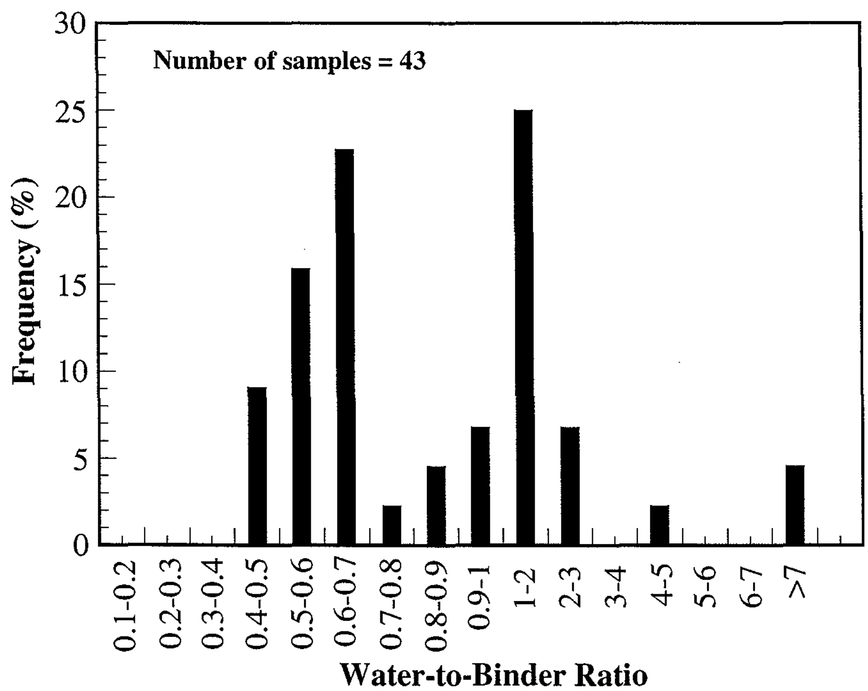


Figure 4.2 Variation of water-to-binder ratio for flowable fill with FS (Literature review)

strength less than 100 psi. The distributions of the data are shown in Fig. 4.4 and Fig. 4.5. For 56% of the mixes compressive strength was between 50 to 100 psi. Only 4.6% of the mixes had strength over 200 psi (Fig. 4.6).

(e) Summary

Based on the data collected on 43 mixes of flowable fill with Foundry Sand (FS), the following can be concluded:

(1) The highest frequency of water-to-cement ratio used was from 7 to 9. The average water-to-cement ratio was 8.4 with FS.

(2) The most used water-to-binder (cement + fly ash) ratio was from 1 to 2 for mixes with FS. The average water-to-binder ratio was 1.4.

(3) The flow cylinder test was used to determine the flowability of the mix.

(4) The unit weight of the mixes varied from 97 to 127 pcf (1555 to 2036 kg/m^3).

(5) The compressive strength of flowable fill after 28 day of curing varied from 40 to 520 psi (0.3 to 3.6 MPa). The compressive strength was less than 100 psi for 72% of the mixes.

(6) All the studies were limited to the laboratory tests.

4.2 OBJECTIVE

The overall objective is to design and evaluate flowable fill mixes using FS available in Texas. The specific objectives are (1) design and test flowable fills using FS in Texas, (2) determine the properties of field mixes, (3) compare the laboratory and field test results, (4) develop Specification to use FS in flowable fill by TxDOT.

4.3 EXPERIMENTAL PROGRAM

The laboratory-testing program was divided two categories in order to determine the working and engineering properties of the flowable fill. The properties of the flowable fills that were determined are: (1) flowability; (2) unit weight; (3) pulse velocity; and (4) unconfined compressive strength. Changes in physical and engineering properties were studied over one year.

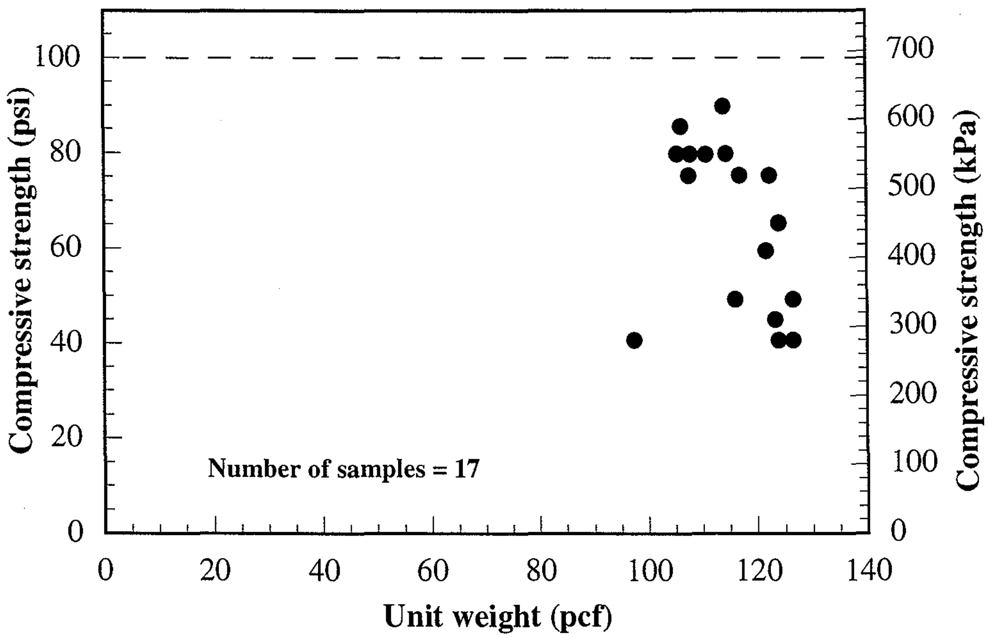


Figure 4.3 Relationship between compressive strength and unit weight (Literature review)

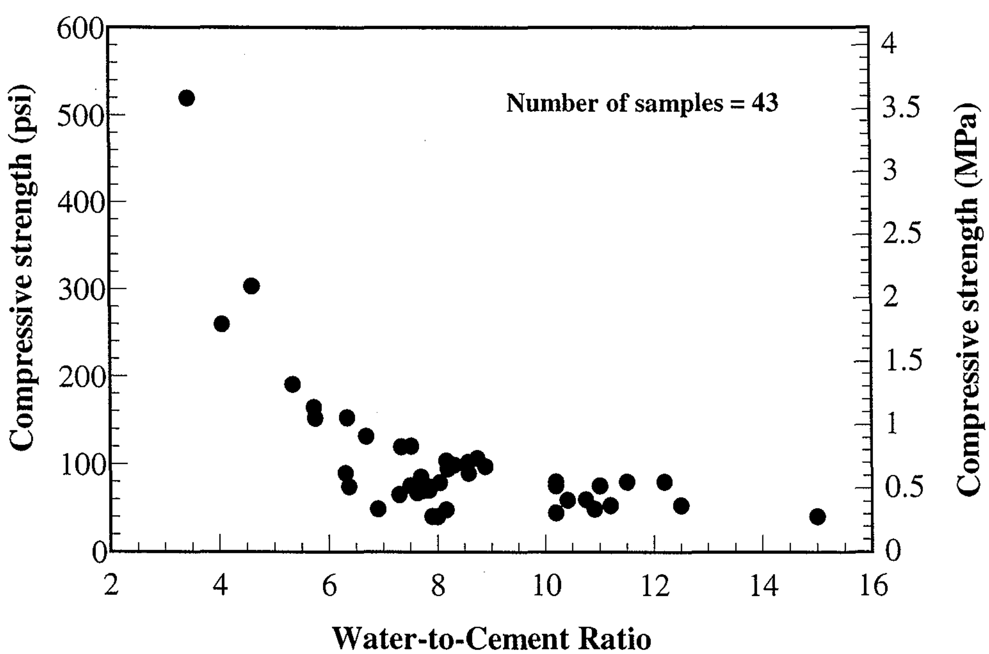


Figure 4.4 Strength versus water-to-cement ratio for the flowable fill with FS (Literature review)

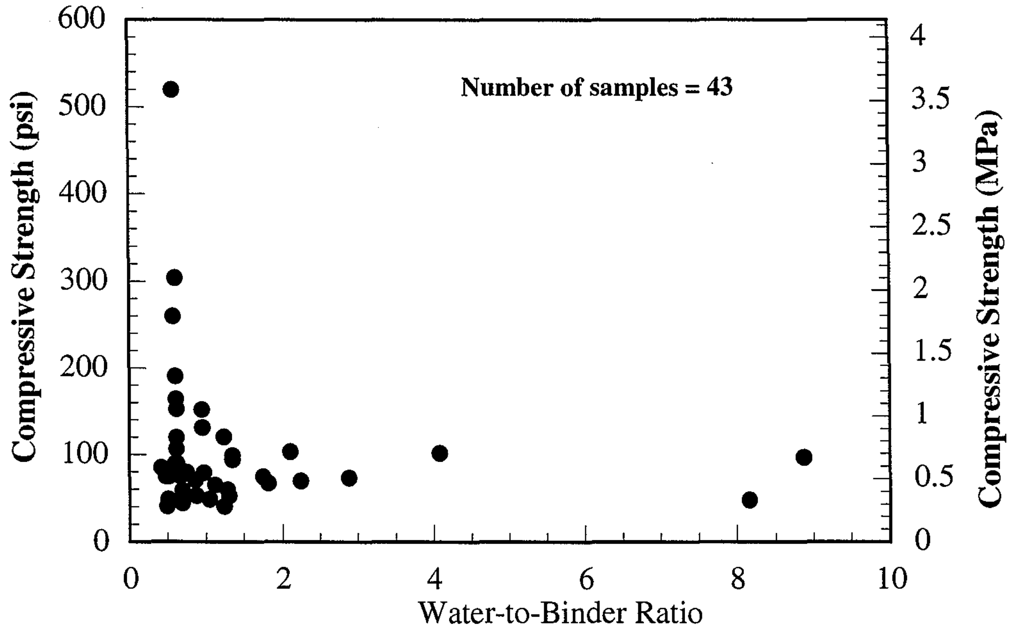


Figure 4.5 Strength versus water-to-binder ratio for the flowable fill with FS

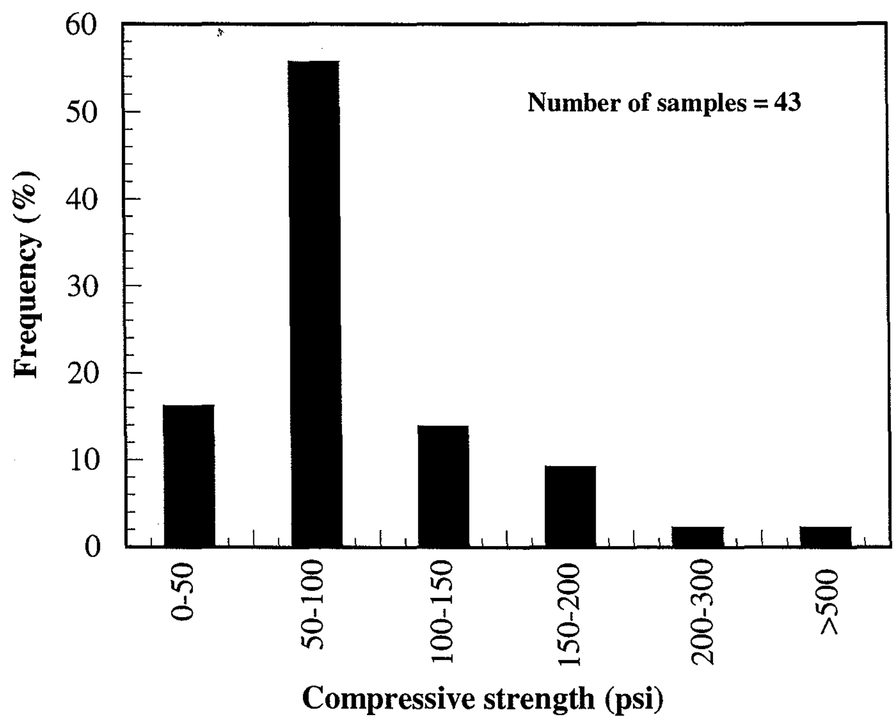


Figure 4.6 Frequency distribution of compressive strength for the flowable fill with FS

4.3.1 Working property

(a) Flowability

Flowability is the property that makes soil-cement flowable fill unique as a fill material and is an important parameter to design the flowable fill. Good flowability is preferred for placing slurry into openings or filling voids. The flowability was determined by two laboratory methods as follows:

(i) Flow Table Test (ASTM D 230)

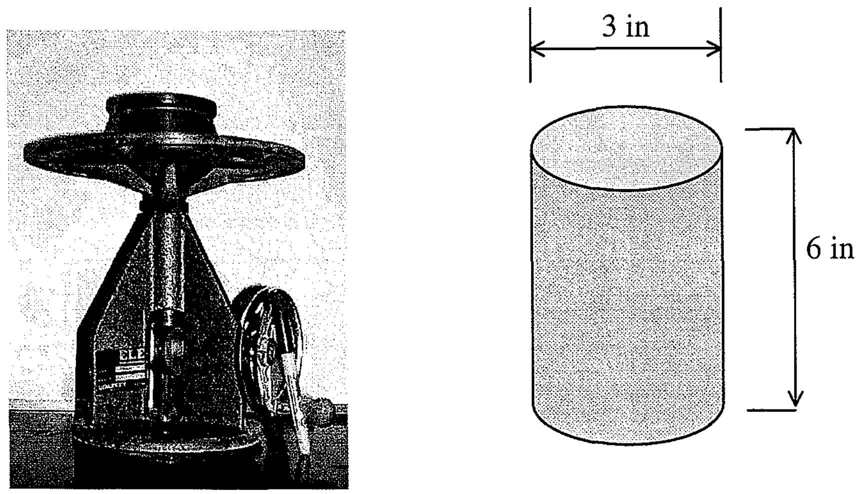
In the table method (ASTM C 230), 10 inches diameter table is used in determining the flowability of hydraulic cement mortars and cement pastes. A shape of flow table is shown in Fig. 4.7 (a). In this test, the table is raised and dropped 10 times in 6 seconds by rotating the hand wheel continuously at a uniform rate. The sample diameter is measured as an average of four readings. At least, triplicate tests were done for each mix proportion. The flowability was calculated as a percentage using the following flowability relation,

$$Flowability = \frac{NewDiameter - OriginalDiameter}{OriginalDiameter} \times 100 \qquad (4.1)$$

Where, New diameter = average diameter after the test, and equidistant intervals, and the Original diameter was 4 in.

(ii) Flow Cylinder Test (ASTM D 6103)

In 1996, provisional standard was revised and adopted as ASTM standard for testing flow consistency of controlled low strength material (D 6103). This test cylinder used in ASTM D 6103 is shown in Fig. 4.7 (b), and Fig. 4.8. The procedure consists of placing a 3" diameter × 6" long open-ended cylinder vertically on a level surface and filling the cylinder to the top with the flowable fill material. The cylinder is then lifted vertically, to allow the material to flow out onto the level surface. Good flowability is achieved when there is no noticeable segregation and the material spread is at least 8 in. in diameter. Three tests were done for each mixture. By the definition when the flow is 8 in. diameter, the flowability is 100%. Hence the relationship can be represented as,



(a) Flow Table (ASTM D 230)   (b) Flow Cylinder (ASTM D 6103)

Figure 4.7 Flowability equipments used in this study

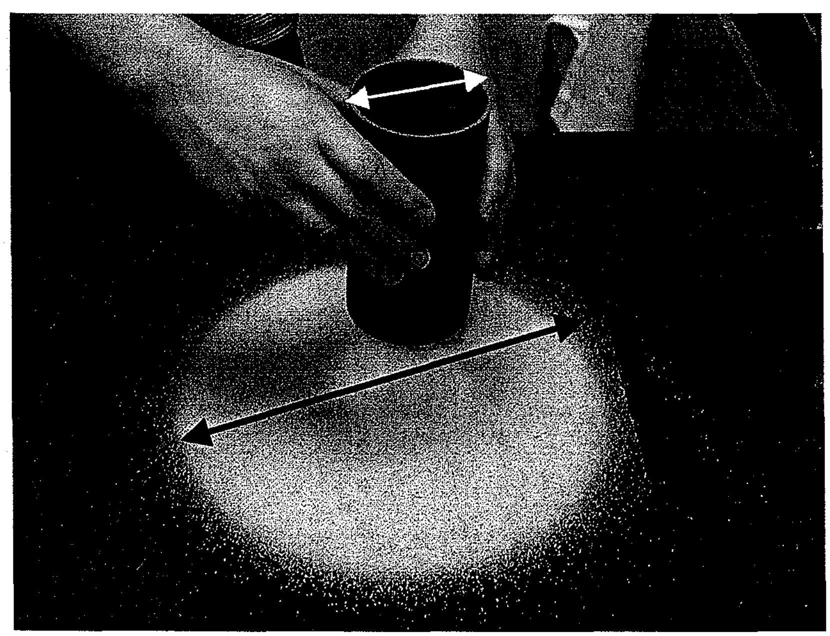


Figure 4.8 Flowability test with Ottawa sand (Flow Cylinder, ASTM D 6103)

$$Flowability = \frac{NewDiameter - OriginalDiameter}{5} \times 100 \qquad (4.2)$$

Where, New diameter = average diameter (2 perpendicular measurements), and

Original diameter = 3 in.

4.3.2 Engineering properties

(a) Unit weight (ASTM D 6023)

The test method explains determination of the mass per cubic foot (cubic meter) of freshly mixed Controlled Low Strength Material (CLSM). This test method is based on Test Method C 138 for Concrete.

(b) Pulse velocity (ASTM C 597)

The test method covers the determination of the pulse velocity of propagation of compressional waves in the solidified flowable fill material. Pulses of compressional waves are generated by an electro-acoustical transducer that is held in contact with one surface of the specimen under test. After traversing through the material, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer. The transit time T was measured electronically. The pulse velocity V was calculated by dividing L by T. The testing apparatus is shown in Fig. 4.9 and Fig. 4.10 consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, a time display unit, and connecting cables

(c) Unconfined Compressive Strength (ASTM D 2166)

Unconfined compressive strength (UCS) is an important parameter when designing the flowable fill. The compressive strength of the flowable fill is an important property that relates directly to the quality of the material. As shown in Fig. 4.11, cylindrical samples were used to measure the unconfined compressive strength of the flowable fill mixtures. Tests were performed on samples cured for at least 2 days.

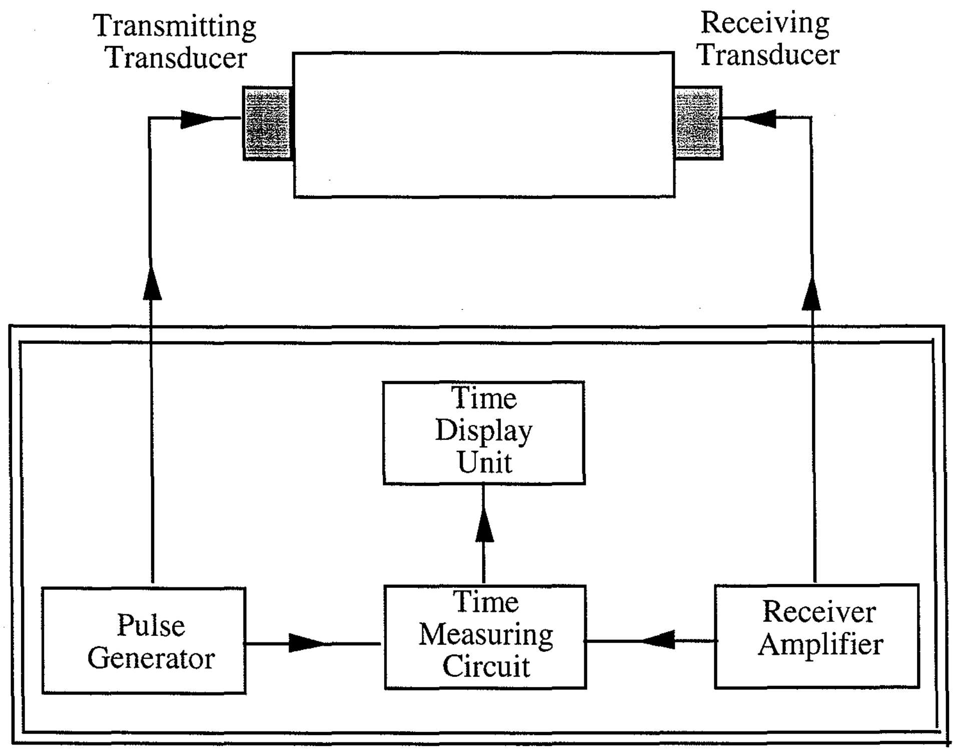


Figure 4.9 Schematic of the pulse velocity testing set up

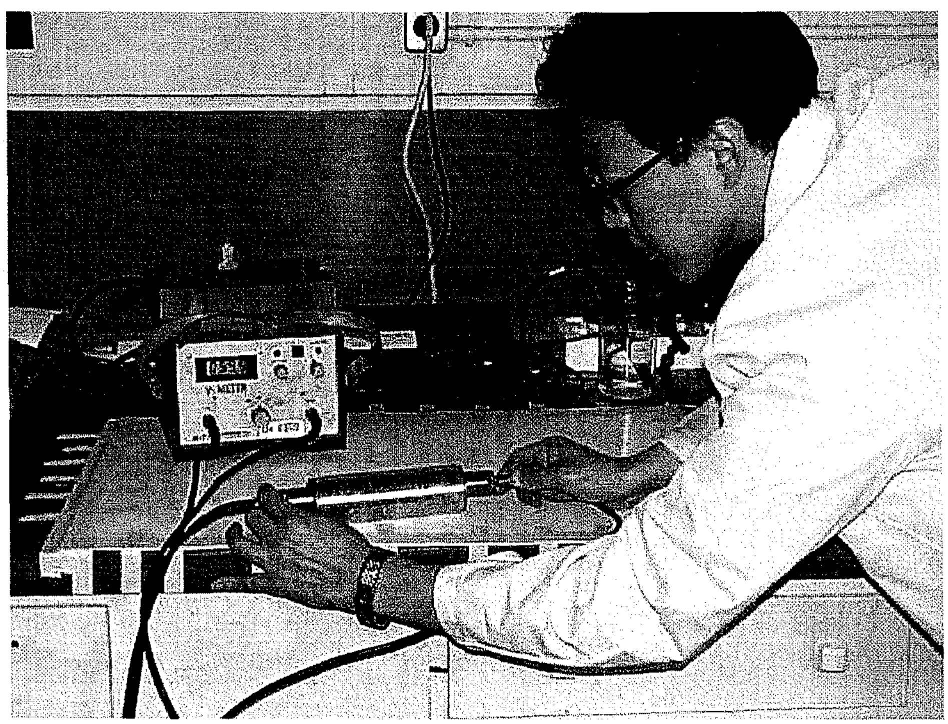


Figure 4.10 Calibrating the pulse velocity tester

4.4 LABORATORY STUDY

The feasibility of using FS in flowable fill mixtures was investigated. Total of 17 FS-cement mixtures (Table 4.3) designed based on literature review and experience. Also FS-Cement-Kaolinite and FS-Cement-Fly ash mixtures were used in the flowable fill mixtures to evaluate their performance.

4.4.1 Flowable fill: FS-Cement mixture

FS-Cement mixtures were designed by changing the water content to achieve 100% flowability using the flow cylinder method (ASTM D 6103, CIGMAT FF 1-99).

4.4.1.1 Working property

(a) Flowability

Flow cylinder (ASTM D 6103) tests were performed on each type of FS sands selected for detailed laboratory tests (Batch FF-1 (FS-9a), Batch FF-2 (FS-9b), and Batch FF-3 (FS-11). Water was added to the mixes to achieve a flowability 100% and the mixes are summarized in Table.4.4. As shown in Fig. 4.12, Batch FF-2 (FS-9b) needed more water to achieve the 100 % flowability as compared to Batch FF-1(FS9-a) and Batch FF-3(FS-11). It should be noted that since Batch FF-2 (FS-9b) had more fine particles compared to Batch FF-1(FS9-a) and Batch FF-3(FS-11), more water was needed to achieve the flowability 100%. To evaluate flowable characteristics of flowable fill with time, flowability of Mix #10 (Batch FF-3 (FS-11) was measured after 1hr, 2 hrs, and 12 hrs of mixing. As shown in Fig. 4.13 and 4.14, flowability decreased with time.

4.4.1.2 Engineering properties

Variation of unit weight, pulse velocity, and unconfined compressive strength with curing time for each batch are summarized in Tables 4.5, 4.6 and 4.7.

(a) Unit weight

The unit weight of all mixtures varied between 73 to 102 lb/ft^3.

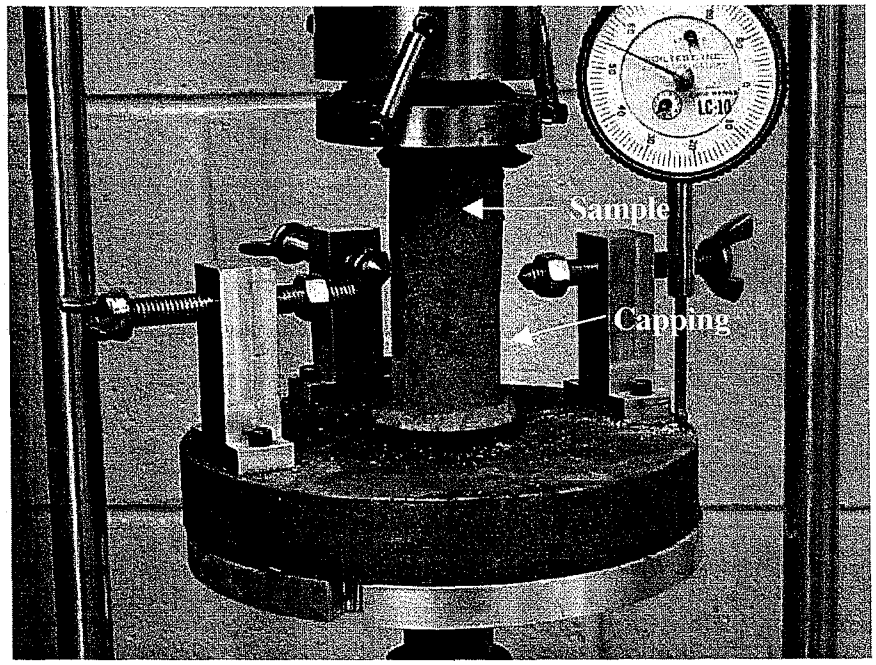


Figure 4.11 Unconfined compressive strength test

Table 4.3 Mixes used in the testing program

Batch # (FS)	Mix number	Mix ratio (by weight)	Remarks
FF-1 (FS-9a)	1	1:8:5 (C:FS:W)	FS-Cement mix
	2	1:12:8 (C:FS:W)	
	3	1:20:8 (C:FS:W)	
FF-2 (FS-9b)	4	1:8:5.5 (C:FS:W)	
	5	1:4:4:3.55(C:FS:S:W)	
	6	1:10:8.2(C:FS:S:W)	
	7	1:12:10.7(C:FS:S:W)	
FF-3 (FS-11)	8	1:8:2.5(C:FS:S:W)	
	9	1:10:3.4(C:FS:S:W)	
	10	1:12:4(C:FS:S:W)	
FF-4 (FS-3)	11	1:16:4:7(C:FS:KC:W)	FS-Cement-Kaolinite mix
	12	1:16:4:4:0.1(C:FS:KC:W:SNF)	
	13	1:16:4:8(C:FS:KC:W)	
	14	1:16:4:5:0.1(C:FS:KC:W:SNF)	
FF-5 (FS-3)	15	1:33:5.7:6.7(C:FS:F:W)	FS-Cement- Fly ash mix
	16	1:50:9:9(C:FS:F:W)	
	17	1:50:9:11(C:FS:F:W)	

FF: Flowable Fill

C: cement, F: Fly ash, FS: Foundry Sand, W:Water, SNF: Superplasticizer

Mix 1- Mix 16: Flowability 100%, Mix 17: Flowability 130%

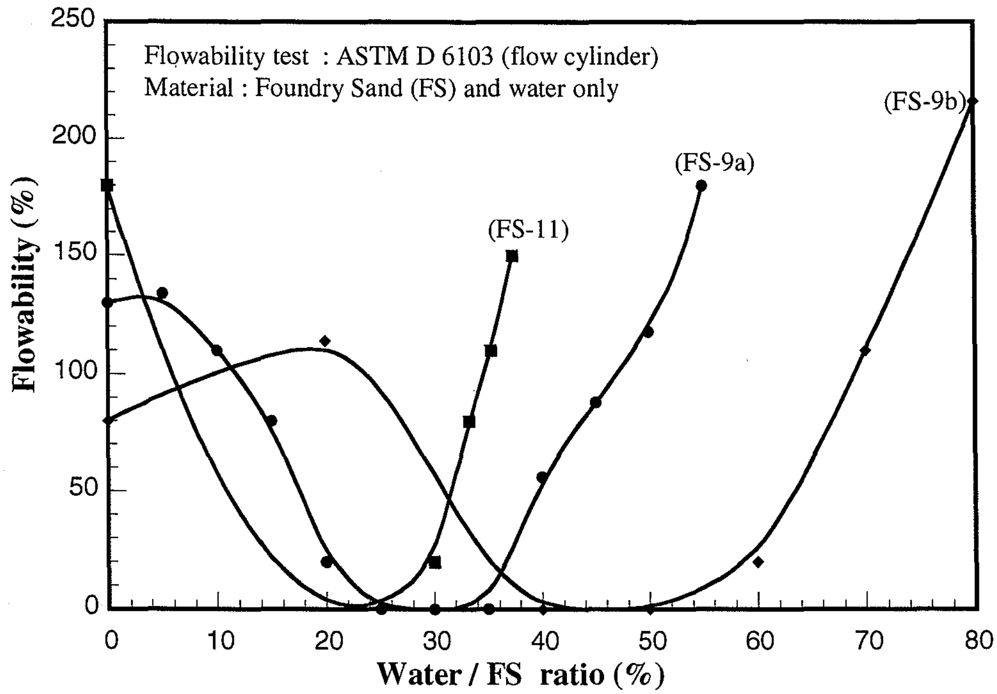


Figure 4.12 Flowability of FS with varying water/FS ratio

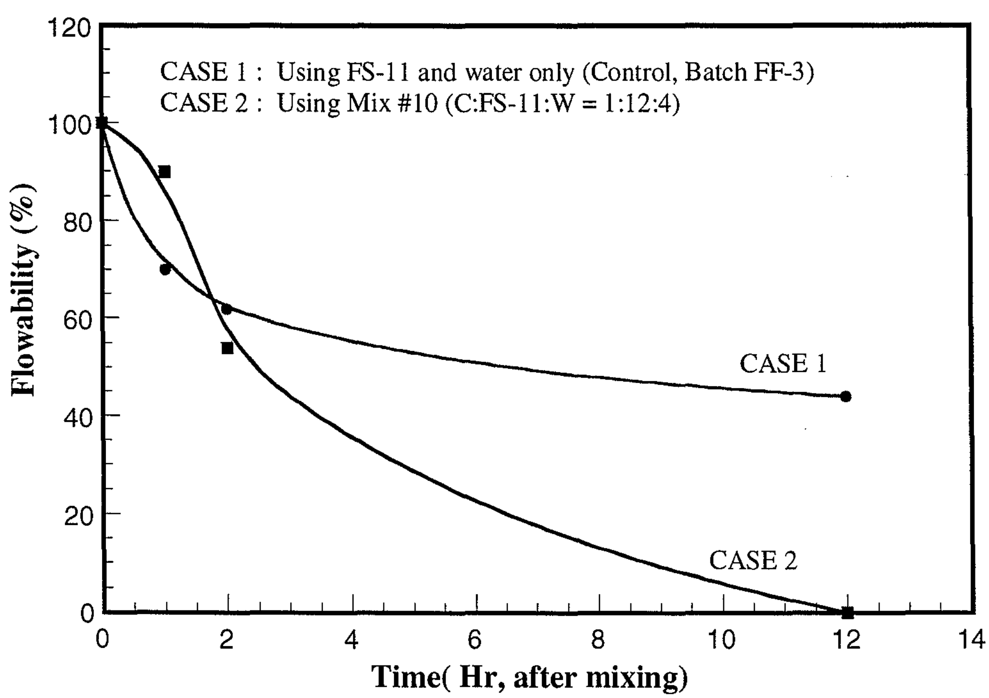


Figure 4.13 Flowability versus time for Batch FF-3

Mix #8 (Batch FF-3 (FS-11)) had the highest unit weight compared to other mixes. As shown in Fig. 4.15, unit weight decreased with increasing the curing time. Mix #7 had the maximum change in unit weight during the curing time between 7 and 28 days. For Mix #7, the 7 day average unit weight of 85 pcf decreased by 10% to 76 pcf after 28 days of curing. As summarized in Table 4.6, and shown in Fig. 4.15, because of initial high water content, unit weight of Mix #7 decrease with increasing curing time. The unit weight of Mix #8 (102 pcf) did not change during the curing time between 7 and 28 days. The average 7 day unit weight of all Mixes of 92.7 pcf decreased by 3.8 % to 89.2 pcf after 28 days of curing.

Mix #6 had the maximum change of unit weight during the curing time between 28 and 180 days. For Mix #6, the 28 day average unit weight of 87 pcf decreased by 17% to 72 pcf after 180 days of curing. The average 28 day unit weight of all Mixes of 89.2 pcf decreased by 12 % to 78.4 pcf after 180 day of curing. Mix #3 had the maximum change of unit weight during the curing time between 180 days and 1 year. For Mix #3, the 180 day average unit weight of 79 pcf decreased by 5% to 75 pcf after 1 year of curing. The average 180 day unit weight of all Mixes of 78.4 pcf decreased by 2.3 % to 76.6 pcf after 28 days of curing.

Unit weight of Batch FF-1 (Mix #1, #2, and #3) mixes had the maximum change during the curing period of 28 and 180 days. Unit weight of Batch FF-2 (Mix #4, #5, #6, and #7) mixes had the maximum change during the curing time of 7 and 28 days.

From the 28 days to 180 days curing time, the average unit weights of all Mixes decreased compared to other curing period. The reason that the unit weight decrease with increasing curing time is that flowable fill mixes had high water content and as a results of curing, water content decreased . As unit weight decreased, pulse velocity also decreased slightly as shown in Fig. 4.16. Inspection of the specimen s showed that It also show that flowable fill has micro-crack inside specimen.

(b) Pulse velocity

The variation of pulse velocity (V_p) of Batch FF-1 (FS-9a,), FF-2 (FS-9b), and FF-3 (FS-11) with the compressive strength (σ_c) is summarized in Table 4.5-4.7. The Pulse velocity of all mixtures varied between 738 to 3696 ft/sec. Mix #8 (Batch FF-3, FS-11)

Table 4.4 Mixture proportion of each Batch (by weight)

BATCHES					
Batch FF-1 (FS-9A)		Batch FF-2 (FS-9B)		Batch FF-3 (FS-11)	
Mix #1	C:FS:W= 1: 8:5	Mix #4	C:FS:W= 1:8:5.5	Mix #8	C:FS:W= 1:8:2.5
Mix #2	C:FS:W= 1 : 12 : 8	Mix #5	C:FS:S:W= 1:4:4:3.55	Mix #9	C:FS:S:W= 1:10:3.4
Mix #3	C:FS:W= 1 : 20 : 8	Mix #6	C:FS:W= 1: 10: 8.2	Mix #10	C:FS:W= 1: 12: 4.0
		Mix #7	C:FS:W= 1:12: 10.7		
Control	FS:W= 1:0.5	Control	FS:W= 1:0.7	Control	FS:W= 1:0.35

- Each mix was selected based on the flowability of 100%
- Mix #5: 50% of FS was replaced with ASTM C 33 sand
- C: Portland Cement, FS: Foundry Sand, W: Water, S: ASTM C 33 Sand
- Control: FS and water only

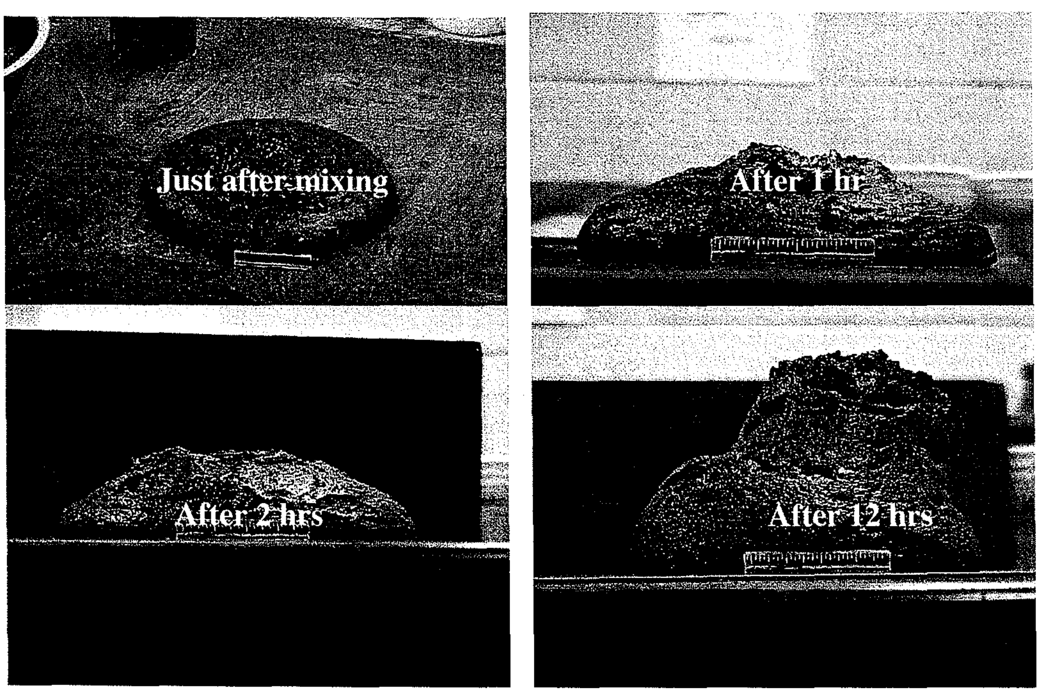


Figure 4.14 Change in flowability of Mix #10 with time

Table 4.5 Engineering properties of Batch FF-1 (FS-9a)

Batch FF-1		Curing time			
		7-day	28-day	6-month	1 year
Mix #1 C:FS:W =1:8:5	Unit weight (lb/ft^3)	87.4	85	78	77
	Pulse velocity (ft/sec)	2975	2030	1950	1800
	Compressive strength (psi)	#1 : 73 #2 : 99 Aver : 86	#1 : 86 #2 : 94 Aver : 90	7#1 : 78 #2 : 128 Aver : 103	#1 : 70 #2 : 75 Aver : 73
	Moisture content (%)	15.5	12	3.1	3.0
Mix #2 C:FS:W =1:12:8	Unit weight (lb/ft^3)	88	85	77	74
	Pulse velocity (ft/sec)	1903	2120	2400	1400
	Compressive strength (psi)	#1 : 46 #2 : 54 Aver : 50	#1 : 55 #2 : 56 Aver : 56	#1 : 61 #2 : 64 Aver : 62	#1 : 40 #2 : 35 Aver : 37
	Moisture content (%)	18.5	14.2	3.0	2.9
Mix #3 C:FS:W =1:20:8	Unit weight (lb/ft^3)	91	86	79	75
	Pulse velocity (ft/sec)	738	1100	1220	750
	Compressive strength (psi)	#1 : 28 #2 : 36 Aver : 32	#1 : 34 #2 : 36 Aver : 35	#1 : 35 #2 : 37 Aver : 36	#1 : 28 #2 : 30 Aver : 29
	Moisture content (%)	19	15	3.0	2.9

Table 4.6 Engineering properties of Batch FF-2 (FS-9b)

Batch FF-2		Curing time			
		7-day	28-day	6-month	1 year
Mix #4 C:FS:W =1:8:5.5	Unit weight (lb/ft^3)	92.6	87	80	78
	Pulse velocity (ft/sec)	2950	2650	2600	1680
	Compressive strength (psi)	#1 : 87 #2 : 96 Aver : 93	#1 : 84 #2 : 100 Aver : 92	#1 : 81 #2 : 93 Aver : 87	#1 : 74 #2 : 82 Aver : 78
	Moisture content (%)	20	13	3	3.0
Mix #5 C:FS:S:W =1:4:4:3.55	Unit weight (lb/ft^3)	96	93	90	89
	Pulse velocity (ft/sec)	2270	2030	1950	1640
	Compressive strength (psi)	#1 : 65 #2 : 71 Aver : 67	#1 : 77 #2 : 79 Aver : 78	#1 : 116 #2 : 124 Aver : 120	#1 : 46 #2 : 76 Aver : 61
	Moisture content (%)	6.2	3.4	3.3	3.1
Mix #6 C:FS:W =1:10:8.2	Unit weight (lb/ft^3)	92	87	72	71
	Pulse velocity (ft/sec)	2148	2040	1970	1970
	Compressive strength (psi)	#1 : 62 #2 : 88 Aver : 75	#1 : 70 #2 : 78 Aver : 74	#1 : 75 #2 : 85 Aver : 80	#1 : 62 #2 : 70 Aver : 66
	Moisture content (%)	46	38	3	2.9
Mix #7 C:FS:W =1:12:10.7	Unit weight (lb/ft^3)	85	76	73	72
	Pulse velocity (ft/sec)	1636	1608	1581	1425
	Compressive strength (psi)	#1 : 55 #2 : 65 Aver : 60	#1 : 53 #2 : 59 Aver : 56	#1 : 49 #2 : 61 Aver : 55	#1 : 45 #2 : 49 Aver : 47
	Moisture content (%)	50	32	4	3.1

Table 4.7 Engineering properties of Batch FF-3 (FS-11)

Batch FF-3		Curing time	
		7-day	28-day
Mix 8 C:FS:W =1:8:2.5	Unit weight (lb/ft^3)	102	102
	Pulse velocity (ft/sec)	3696	3390
	Compressive strength (psi)	#1 : 295 #2 : 364 Aver : 340	#1 : 297 #2 : 303 Aver : 300
	Moisture content (%)	4.4	2.5
Mix 9 C:FS:W =1:10:3.4	Unit weight (lb/ft^3)	98	96
	Pulse velocity (ft/sec)	3351	2459
	Compressive strength (psi)	#1 : 184 #2 : 216 Aver : 200	#1 : 146 #2 : 150 Aver : 148
	Moisture content (%)	4.9	2.8
Mix 10 C:FS:W =1:12:4.0	Unit weight (lb/ft^3)	95	94.5
	Pulse velocity (ft/sec)	2620	2008
	Compressive strength (psi)	#1 : 121 #2 : 123 Aver : 122	#1 : 91 #2 : 100 Aver : 96
	Moisture content (%)	4.8	2.9

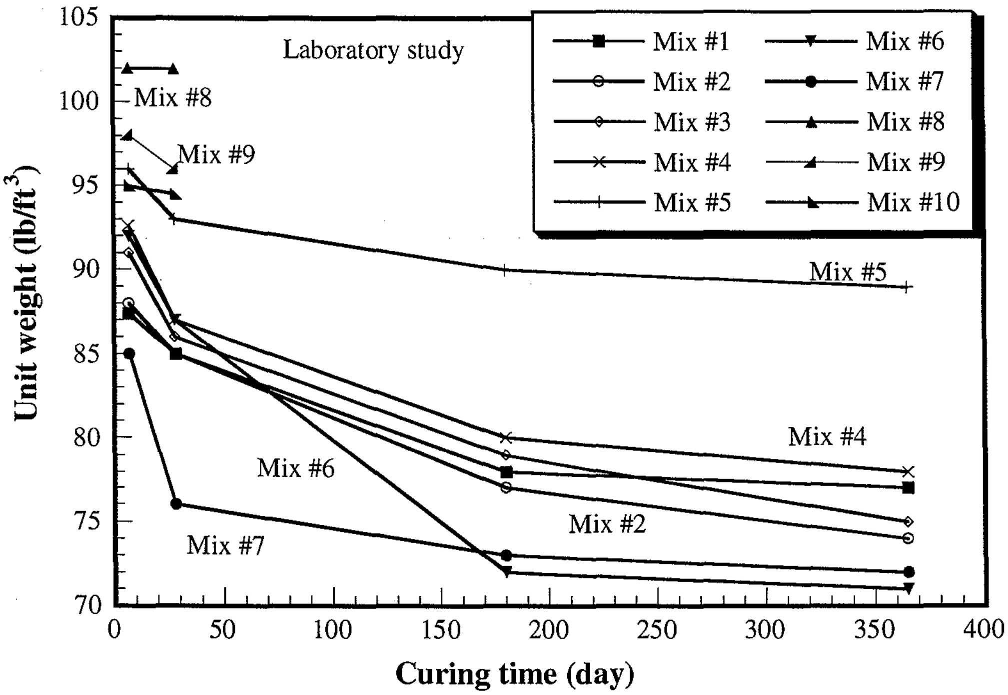


Figure 4.15 Variation of unit weight versus curing time for flowable fill mixtures

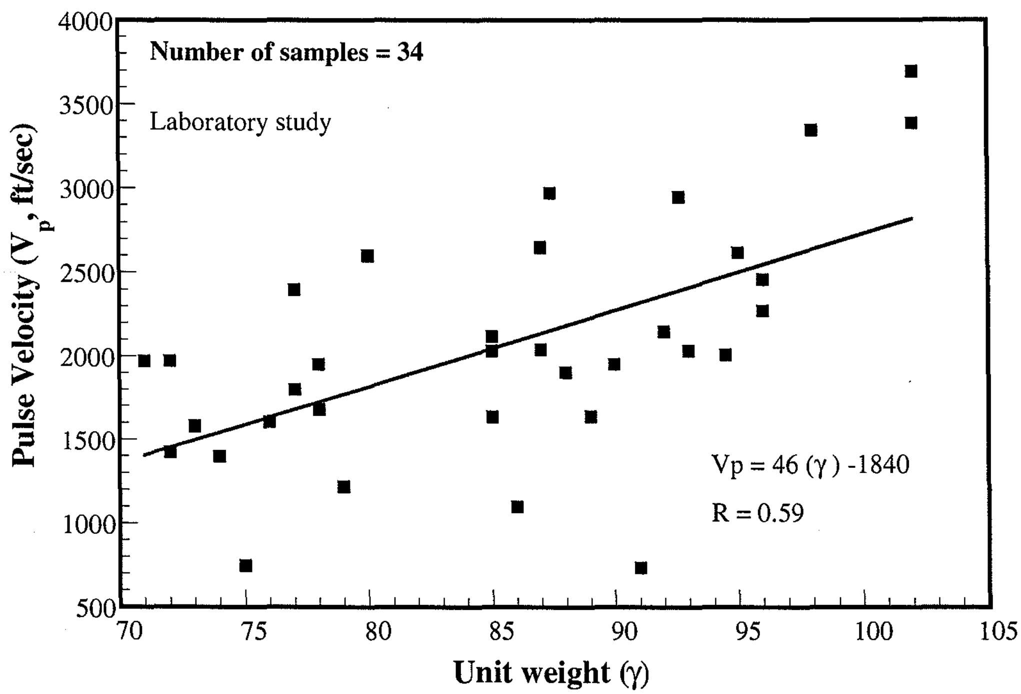


Figure 4.16 Variation of pulse velocity with unit weight

had the highest pulse velocity compared to other mixes. As shown in Fig. 4.17, pulse velocities decreased with increasing curing time except for Mix #2 and Mix #3.

Mix #1 had the maximum change in pulse velocity during the curing time between 7 and 28 days. For Mix #1, the 7 day average pulse velocity of 2975 ft/sec decreased by 32% to 2030 ft/sec after 28 days of curing. Mix #7 had the minimum change of pulse velocity during the curing time between 7 and 28 days. For Mix #7, the 7 day average pulse velocity of 1636 ft/sec decreased by 1.7% to 1608 ft/sec after 28 days of curing. The average 7 day pulse velocity of all Mixes of 2429 ft/sec decreased by 12 % to 2144 ft/sec after 28 day of curing.

Mix #2 had the maximum change in pulse velocity during the curing time between 28 and 180 days. For Mix #2, the 28 day average pulse velocity of 2120 ft/sec increased by 13% to 2400 ft/sec after 180 days of curing. The average 28 day pulse velocity of all Mixes of 2144 ft/sec decreased by 9 % to 1953 ft/sec after 180 days of curing. The average pulse velocities of all Mixes were decreased with increasing the curing time. In general, pulse velocity increased with compressive strength and as shown in Fig. 4.18, pulse velocity was related to compressive strength as follows

$$\sigma_c = 0.077\, V_p - 68.8 \tag{4.4}$$

(c) Unconfined compressive strength

Variation of unconfined compressive strength with curing time for flowable fill mixtures are summarized in Tables 4.5, 4.6, and 4.7. The variation of compressive strength with curing time and other mix ratios are shown in Figs 4.19 through 4.24. The compressive strength of all mixtures varied between 29 to 340 psi. Mix #8 (Batch FF-3 (FS-11)) had the highest unconfined compressive strength compared to other mixes. As shown in Fig. 4.20, 4.22, and 4.24, unconfined compressive strength increased with increasing the curing time during the first 7 days of curing. Mix #10 had the maximum change of unconfined compressive strength during the curing time between 7 and 28 days. For Mix #10, the 7 day average unconfined compressive strength of 122 psi decreased by 21% to 96 psi after 28 days of curing. Mix #6 had the minimum change of unconfined compressive strength during the curing time between 7 day and 28 day.

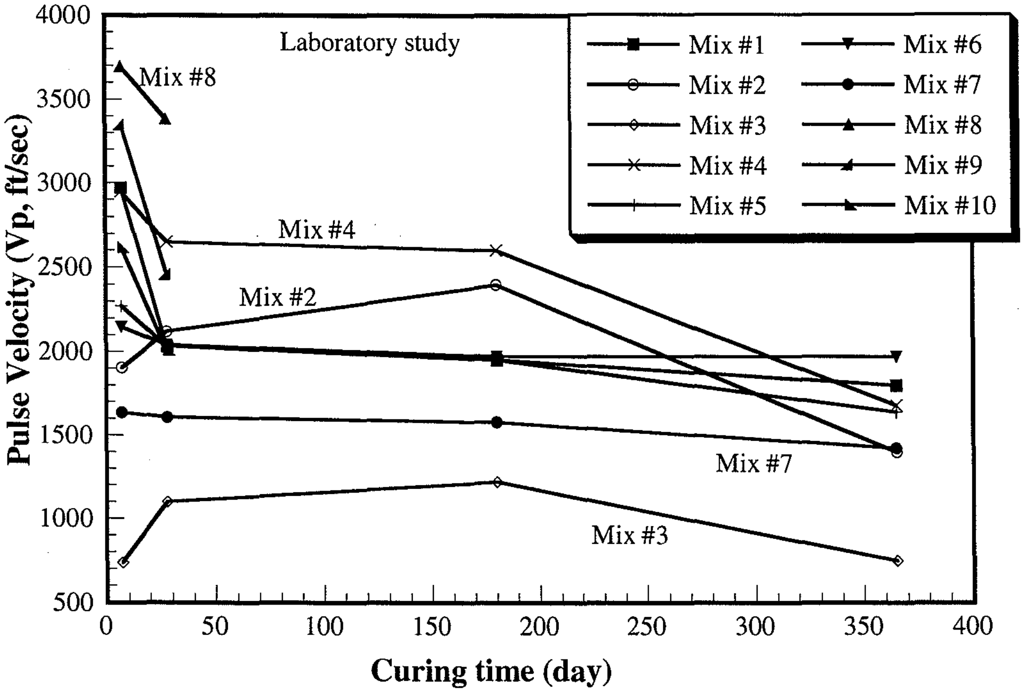


Figure 4.17 Variation of pulse velocity versus curing time for various mixes

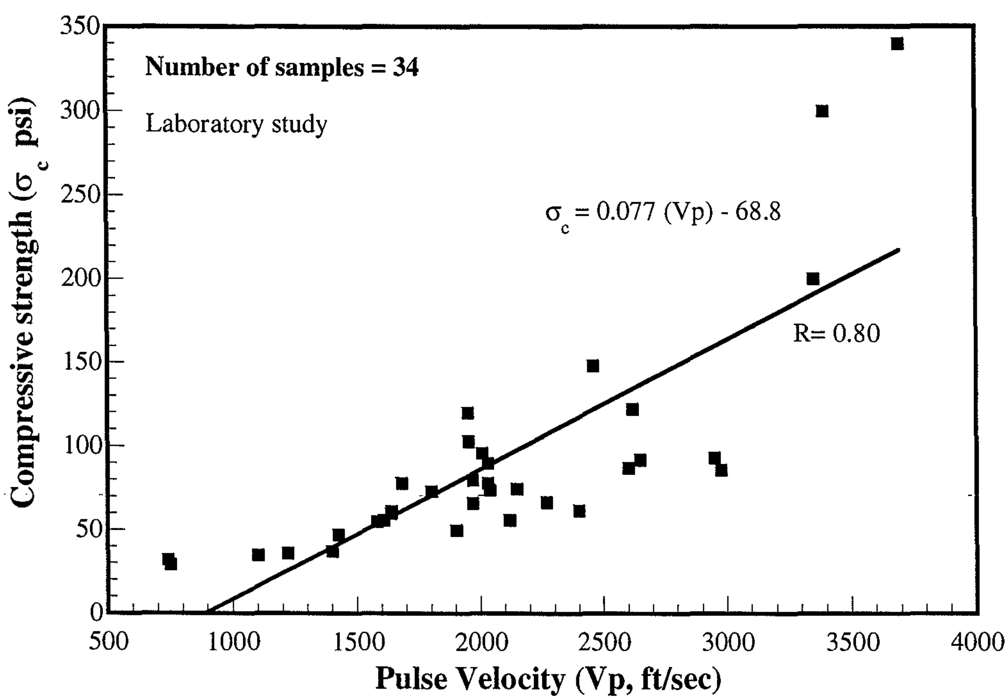


Figure 4.18 Pulse velocity versus compressive strength relationship

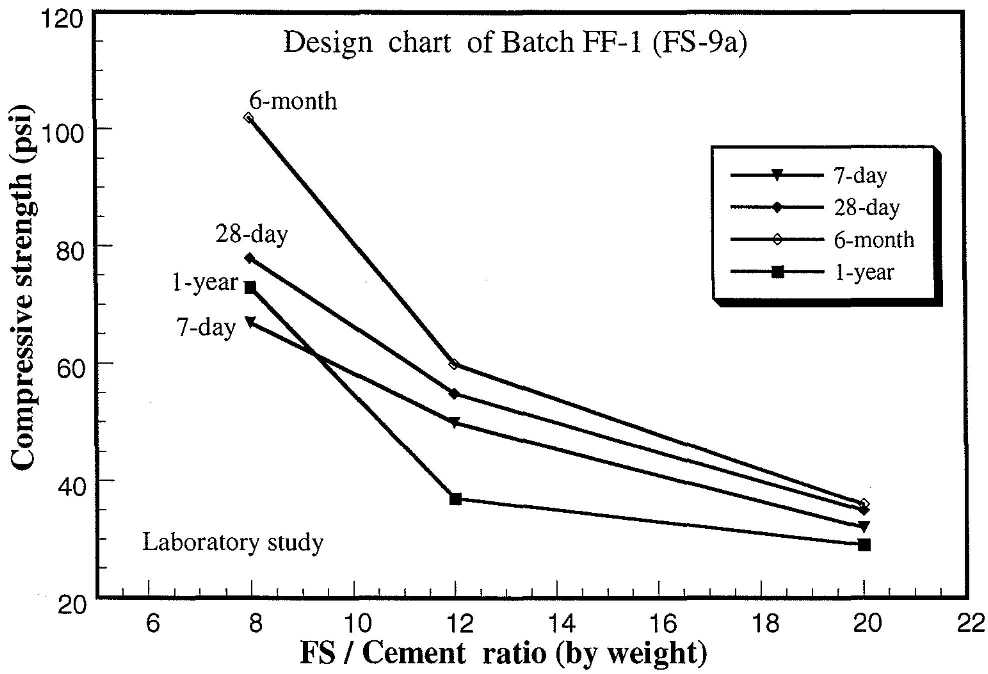


Figure 4.19 FS/cement ratio on the compressive strength of flowable fill (FF-1)

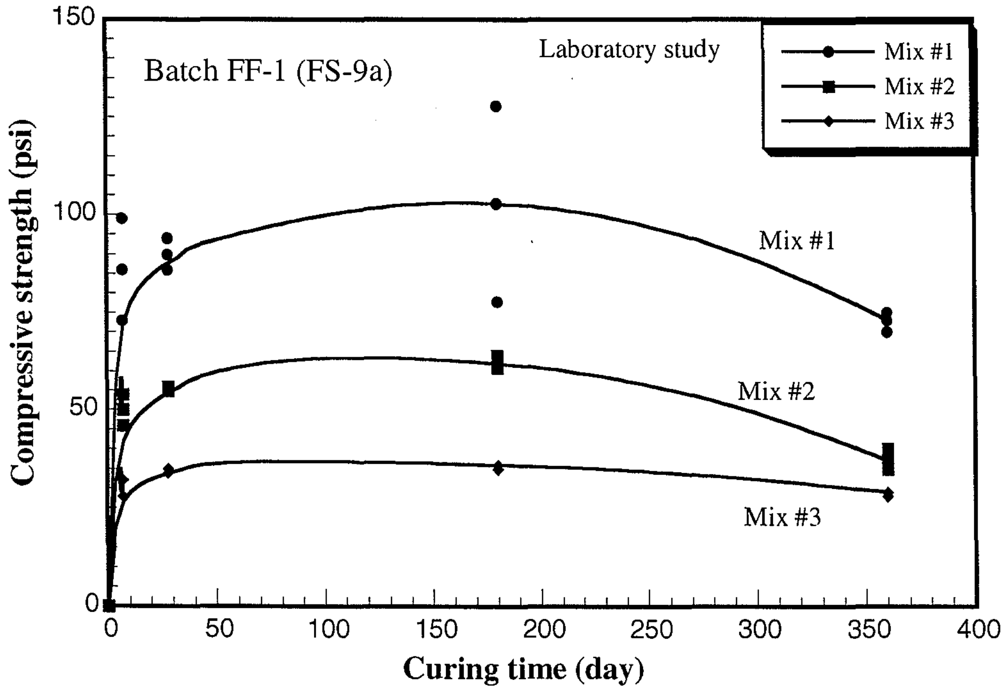


Figure 4.20 Variation of compressive strength with curing time for Batch FF-1

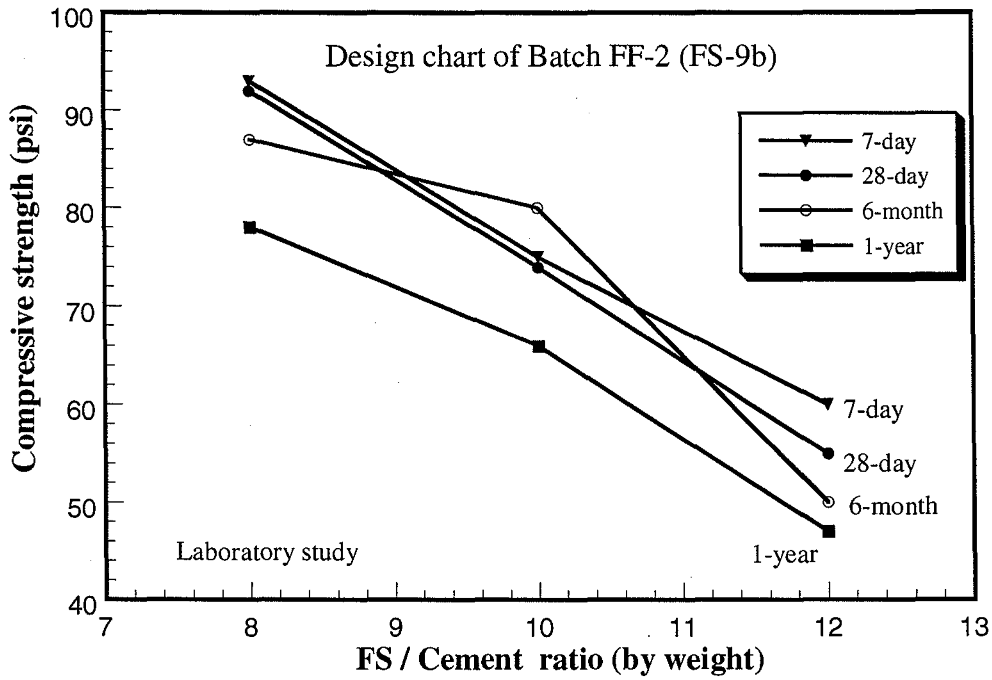


Figure 4.21 FS/cement ratio on the compressive strength of flowable fill (FF-2)

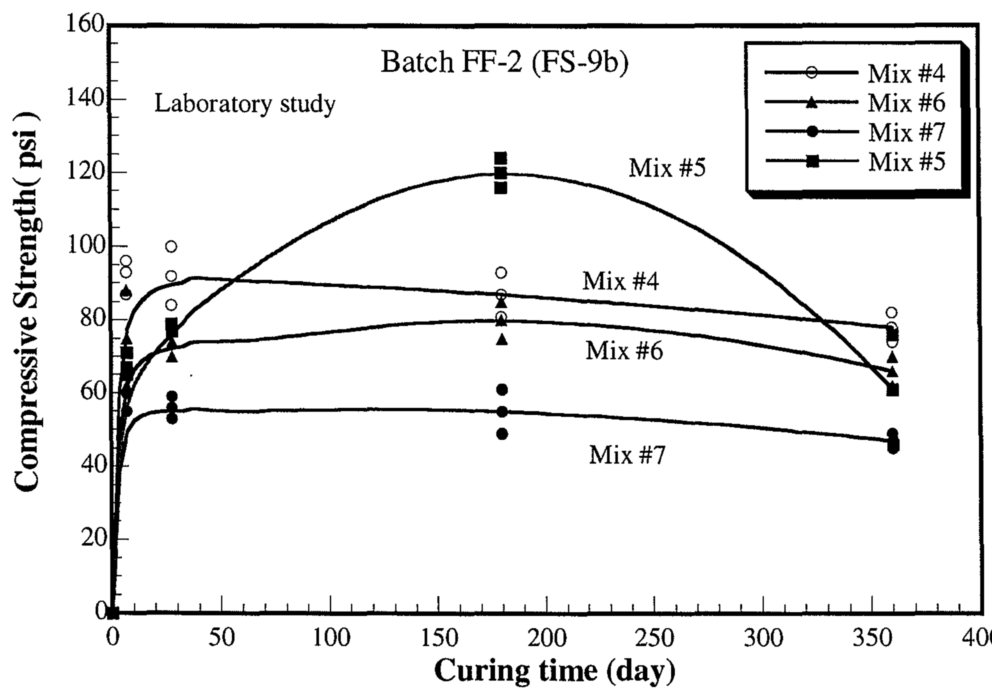


Figure 4.22 Variation of compressive strength with curing time for Batch FF-2

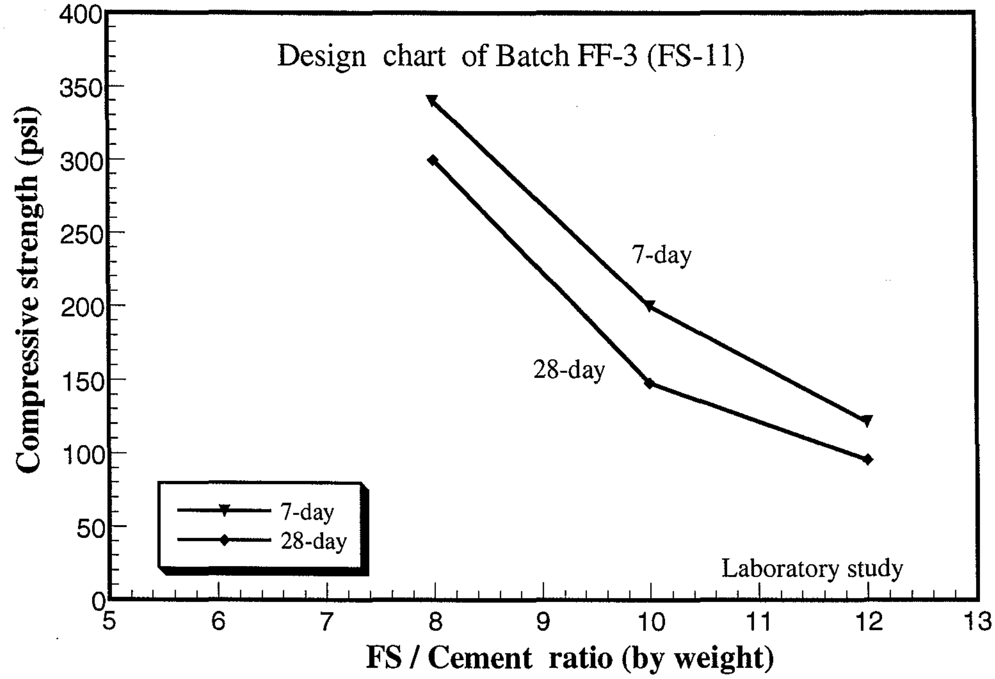


Figure 4.23 FS/cement ratio on the compressive strength of flowable fill (FF-3)

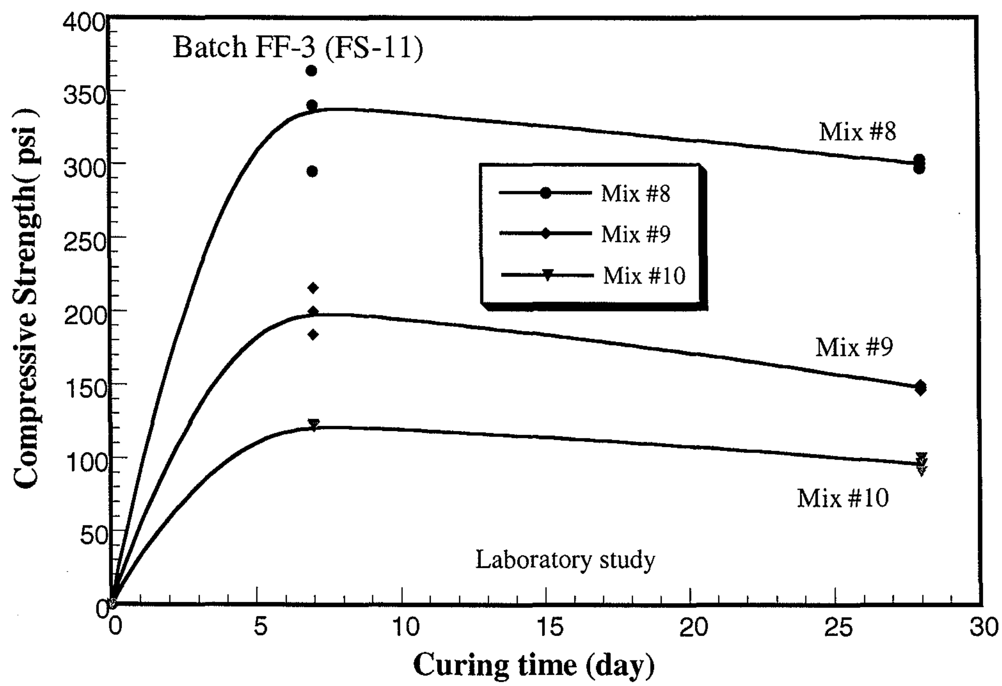


Figure 4.24 Variation of compressive strength with curing time for Batch FF-3

For Mix #6, the 7 day average unconfined compressive strength of 75 psi decreased by 1.3 % to 74 psi after 28 days of curing.

Mix #5 had the maximum change in unconfined compressive strength during the curing time between 28 day and 180 day. For Mix #5, the 28 day average compressive strength of 78 psi increased by 54% to 120 psi after 180 days of curing. Mix #3 had the minimum change in unconfined compressive strength during the curing time between 28 and 180 days. For Mix #3, the 28 day average unconfined compressive strength of 35 psi was unchanged after 180 days of curing. Unconfined compressive strength of Batch FF-1 (Mix #1, #2, and #3) mixes increased with increasing the curing time until 180 days. However, the compressive strength after 1year of curing, decreased. For Mix #1, the 180 day average unconfined compressive strength of 103 psi decreased by 29% to 73 psi after 1 year of curing. As shown in Figs. 4.21 and 4.22, unconfined compressive strength of Batch FF-2 (Mix #4, #5, #6, and #7) mixes decreased with increasing the curing time during the curing time of 1 year. For the Mix #5, 1 year average unconfined compressive strength of 120 psi decreased by 50% to 61 psi after 365 days of curing. As shown in Figs. 4.23 and 4.24, compressive strength of Batch FF-3 (Mix #8, #9, and #10) mixes decreased with the curing time. For Mix #8, the 7 day average compressive strength of 340 psi decreased by 12% to 300 psi after 28 days of curing.

The variation of compressive strength for Batch FF-1, FF-2, and FF-3 with unit weight is shown in Fig. 4.25. There was no direct relationship between compressive strength and the unit weight when the unit weight varied from 70 to 95 pcf. To evaluate the effect of cement content on the compressive strength, the distribution of cement/water ratio and compressive strength are shown in Fig. 4.26. Compressive strength increased with decreasing water / cement ratio. When the water/cement ratio was decreased from 4 to 3, the compressive strength increased from 100 psi to 300 psi. FS/cement ratio was varied from 8 to 20 for Batch FF-1 and varied from 8 to 12 for Batch FF-2 and FF-3.

4.4.1.3 Summary

FS-cement mixtures were tested to evaluate the feasibility of using FS (Foundry Sand) as a flowable fill. Based on the experimental results and analysis of the test data, following conclusions are advanced:

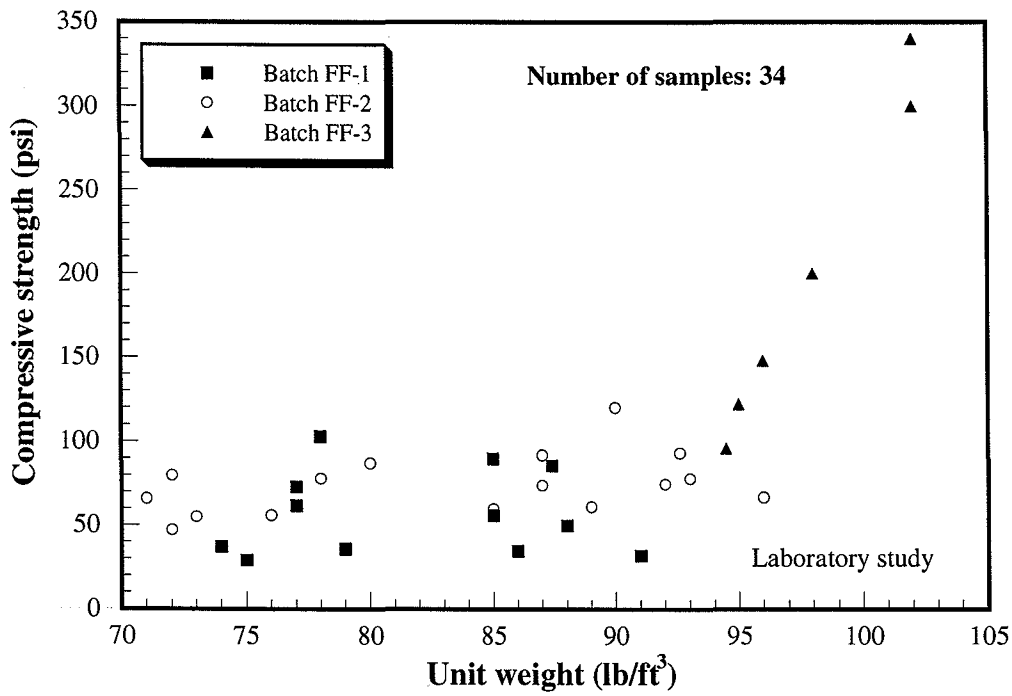


Figure 4.25 Relationship between compressive strength and unit weight

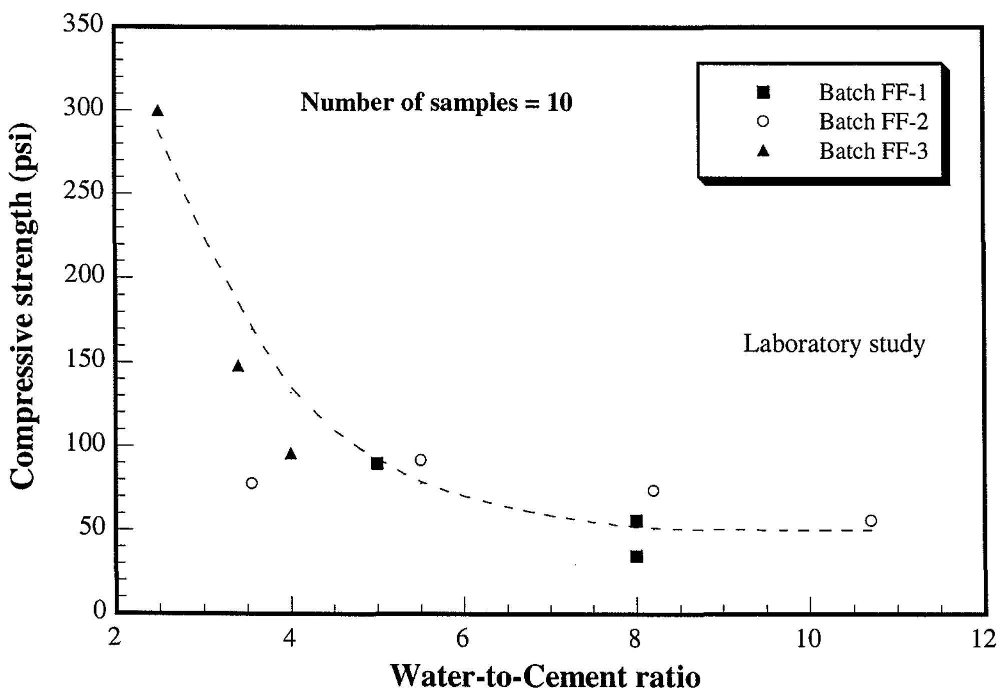


Figure 4.26 Strength versus water-to-cement ratio

1. Flowability: Flowability was influenced by moisture content and type of foundry sand. Batch FF-2 (FS-9b) needed more water to achieve the flowability 100%.
2. Strength: The unconfined compressive strength of the flowable fill increased with curing time at varying rates. Design curves have been developed (Unconfined compressive strength versus cement to sand ratio). For same mixes, compressive strengths decreased after 1 year of curing.
3. Property Relationships: Compressive strength was linearly related to the pulse velocity for the flowable fill.

4.4.2 Flowable fill: FS-Kaolinite-Cement mixture

Mainly sandy soils have been used in flowable fill. But there is increasing interest in evaluating the effect of clay on the flowable fill. Hence kaolinite clay was used in this study.

Two typical blasting sand-cement flowable fill were also studied to compare the engineering properties. These two mixes (Mix B1 and Mix B2) and four Batch FF-4 (FS-3) FS-Cement-Kaolinite mixes are summarized in the Table 4.8. The particle size distribution of FS-3 and blasting sand are shown in Fig. 4.27. Comparing with the blasting sand, the range of these sand grain size was close. The grain size of blasting sand ranged from 0.07 mm to 5 mm and FS-3 was from 0.08 mm to 3 mm. But their particle size distribution was different (Fig. 4.27). Mix #11 and Mix #12 were the same as Mix #B1 and Mix #B2 respectively except the different type of sand.

4.4.2.1 Working property

(a) Flowability

Flow table (ASTM D 230), and flow cylinder (ASTM D 6103) tests were performed on Batch FF-4 flowable fill (Mix #11, #12, #13, #14, #B1, and #B2) and test results are shown in Figs. 4.28 and 4.29. Both Mix #11 and Mix #12 could not reach 100% flowability. In Mix #13 and Mix #14, the water content was increased to achieve good flowability (more than 100% flowability). But the strength decreased slightly. Different types of sands resulted in different flowability.

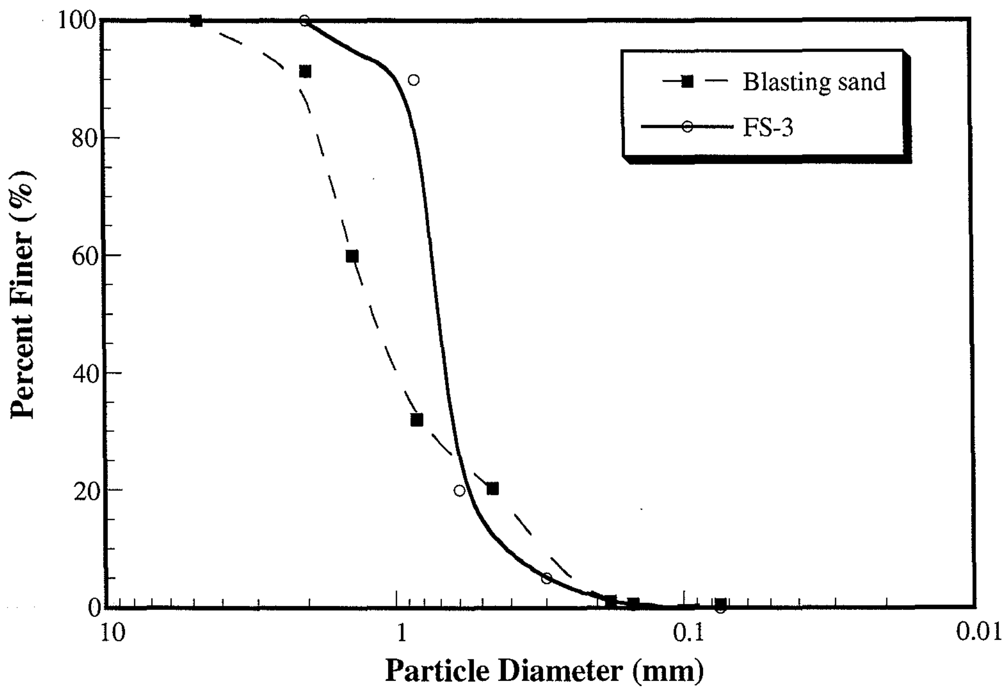


Figure 4.27 The particle size distribution of blasting sand and FS-3

Table 4.8 The different mixture proportion of FS-cement-kaolinite flowable fill

Mix #	Sand Type	Mix Ratio (By weight)						Flowability (%)	
		Cement	Sand	kaolinite	Water	SNF	W/C	Cylinder	Table
11	FS-3	1	16	4	7	0	7	85	89
12	FS-3	1	16	4	4	0.1	4	62	80
13	FS-3	1	16	4	8	0	8	130	107
14	FS-3	1	16	4	5	0.1	5	120	113
B1	Blasting Sand	1	16	4	7	0	7	98	100
B2	Blasting Sand	1	16	4	4	0.1	4	120	97
Remarks	6 mixes	5% cement (dry mix)	76% sand (dry mix)	19% kaolinite (dry mix)	Range: 4 -8	Reduce water needed	Range : 4 -8	Varied 62-130	Varied: 80-113

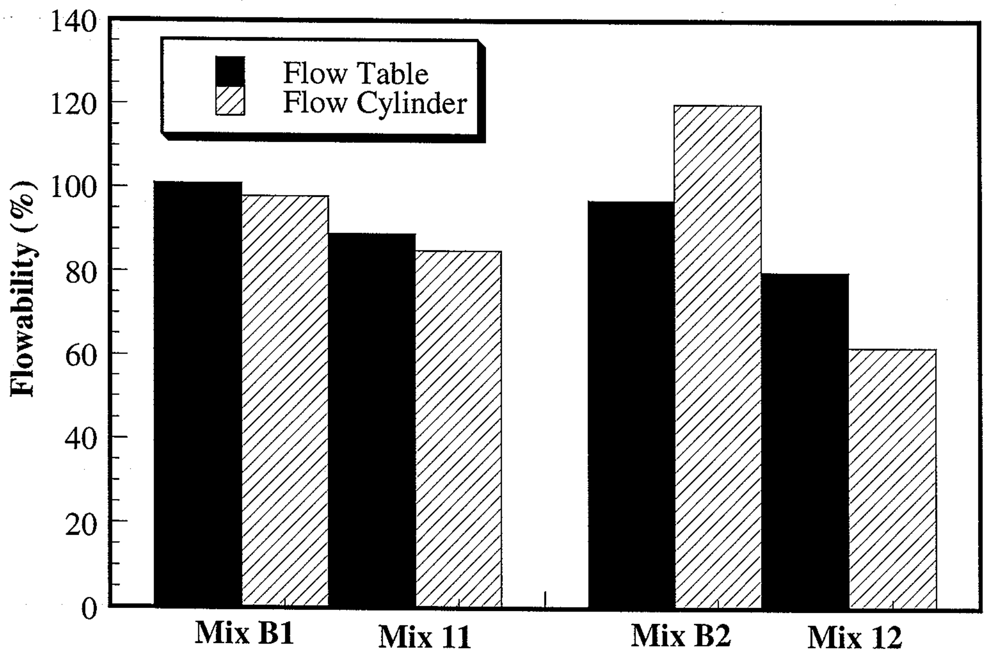


Figure 4.28 The flowability of kaolinite flowable fill with blasting sand and FS-3

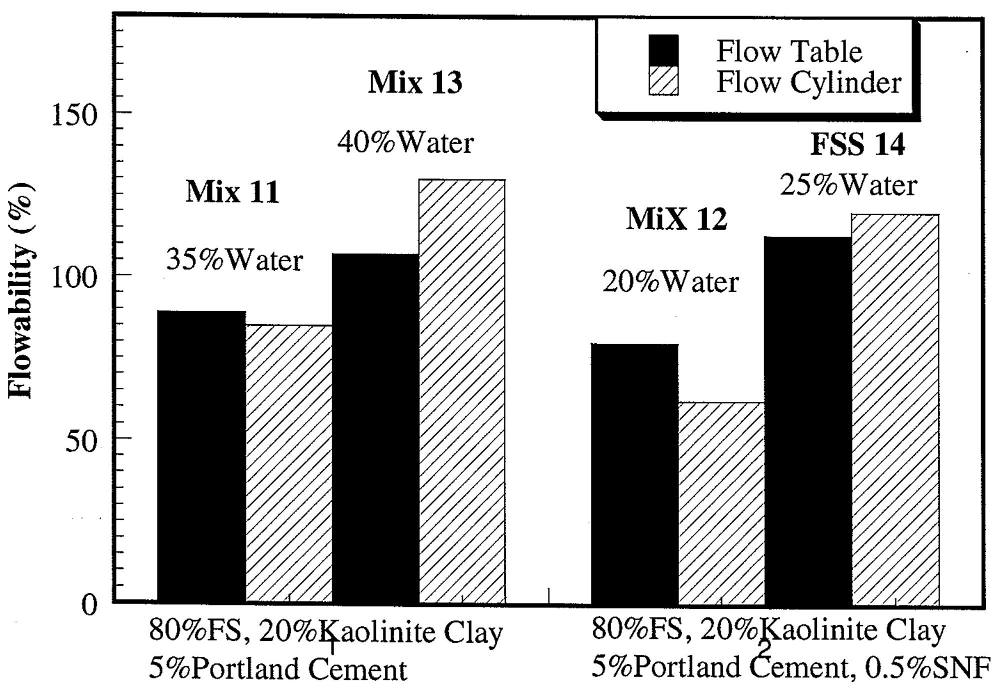


Figure 4.29 The flowability of FS-cement-kaolinite flowable fill with and without superplasicizer (SNF)

Adding a superplasticizer (SNF, Sulfonated Naphthalence Formaldehyde condensates) improved the flowability.

4.4.2.2 Engineering properties

(a) Unconfined compressive strength

The change in unconfined compressive strength with curing time are summarized in Table 4.9 and also shown in Fig. 4.30. The unconfined compressive strength of all mixtures varied between 11 to 151 psi. Mix #12 (Batch FF-4(FS-3)) had the highest unconfined compressive strength compared to other mixes. As shown in Fig. 4.30, unconfined compressive strength increased with curing time. Mix #11 had the maximum change of unconfined compressive strength during the curing time between 7 and 28 days. For Mix #11, the 7 day average unconfined compressive strength of 11 psi increased by 318% to 35 psi after 28 days of curing. Mixtures with superplasticizer (Mix B2, Mix #12, and Mix #14) had much higher strength than those without superplasticizer.

4.4.2.3 Summary

The effect of kaolinite clay on the performance of flowable fill mixture was investigated. Based on the experimental results, the following can be concluded:

1. The unconfined compressive strengths were 140 psi and 25 psi after 28 days of curing for Mix B2 and Mix B1 respectively. Based on the performance of Mix B1 and Mix B2, the superplasticizer (SNF) used in the flowable fill was effective in increasing the compressive strength and decreasing water-to-cement ratio in the mix.

2. Foundry sand was used to replace blasting sand as a major fine aggregate in the flowable fill. Based on the same mixture proportion, Mix 11(FS-3) had lower flowability but similar compressive strength compared with Mix B1. Also Mix #12 (FS-3) had lower flowability and similar strength when compared with Mix B2.

Table 4.9 Engineering properties of FS-cement-kaolinite flowable fill

Batch FF-4 (FS-3)		Curing time	
		7 –day	28-day
Mix #11	Compressive strength (psi)	11	35
	Failure strain (%)	3.0	2.8
	Tangent modulus (ksi)	0.7	1.9
Mix #12	Compressive strength (psi)	51	151
	Failure strain (%)	1.7	1.5
	Tangent modulus (ksi)	6	21.3
Mix #13	Compressive strength (psi)	10	27
	Failure strain (%)	3.3	3.2
	Tangent modulus (ksi)	0.6	1.6
Mix #14	Compressive strength (psi)	42	119
	Failure strain (%)	2.0	1.8
	Tangent modulus (ksi)	3.9	10.6

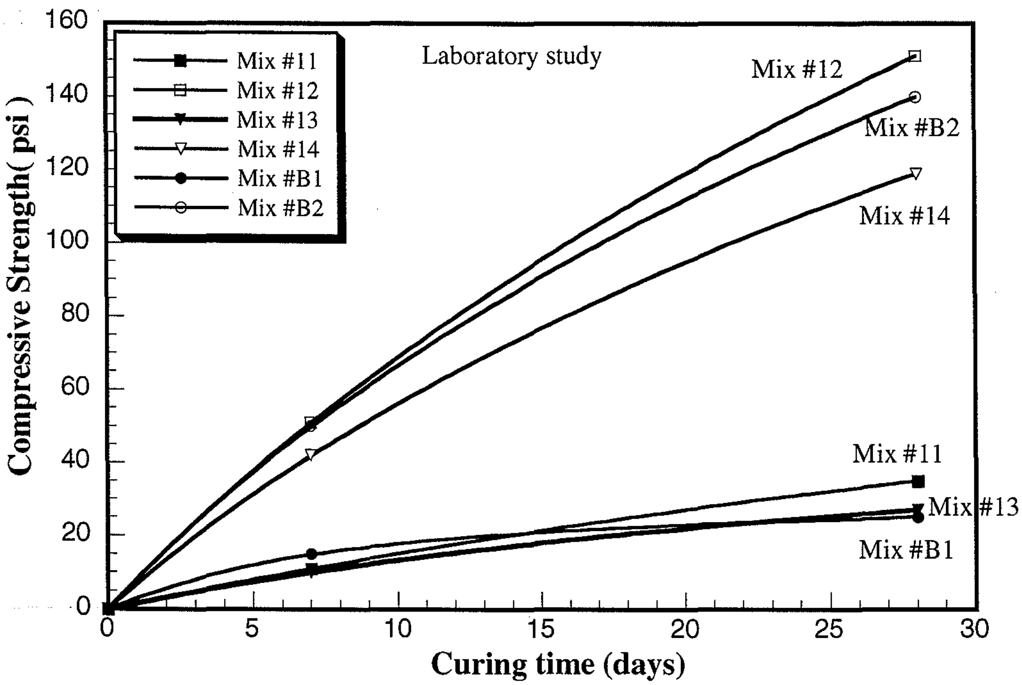


Figure 4.30 The strength versus curing time of for FS-cement-kaolinite flowable fill

4.4.3 Flowable fill: FS-Cement-Fly ash mixture

Cementitious mixtures with good flowability (flowable fill) were developed for various geotechical and structural applications. Flowable fill mixtures are usually made of Portland cement, water, and fine aggregate, or fly ash or both. Sometimes, it also contains admixtures such as fluidifier and superplasticizer. In this study, Batch FF-5 (FS-3) foundry sand was used with fly ash (Class F) in the FS flowable fill. As summarized in Table 4.10, total of 3 mixes of FS-cement-fly ash flowable fill were investigated.

4.4.3.1 Working property

(a) Flowability

The flowability of a mixture should be in a range where it will be possible to easily pump the mixture at preferably low pressure. The bleeding of mixtures should be minimum value so as to keep the mixture stable throughout the process. This study investigates the effect of various admixtures on the flowability, a working property.

Dry Materials: Tests were performed on dry materials to evaluate their flowability and to determine whether the materials could be selected based on these results. Both Flow Table (ASTM C 230) and Flow Cylinder (ASTM D 6103) tests were performed. Flowability of cement, fly ash (Class F) and sand are shown in Fig. 4.31. Based on flow cylinder method, sand and cement showed flowability of slightly above 120%, whereas fly ash had only about 83% flowability. Typical flow shapes for these three materials are shown Fig. 4.32. In the Flow table test, fly ash had the highest flowability of about 120%, whereas sand and cement had flowability of 115% and 85%, respectively.

Based on these limited test results, it can be concluded that cement and fly ash were sensitive to the type of test while sand was not.

Wet Materials: Flowability of wet samples was investigated by changing the water content and the results are shown in Fig. 4.33. Fly ash had 100% flowability at water-to-fly ash ratio of 0.18, whereas the cement had 100% flowability at water-to-cement ratio of 0.35. The flowability of fly ash was much higher than that of cement. The flowability of sand did not change significantly with the increase in water content.

Table 4.10 The different mixture proportion of FS-cement-fly ash flowable fill

Batch FF-5 (FS-3)	Mix Ratio (by weight)				Flowability (Cylinder)
	Cement	FS-3	Fly ash	Water	
Mix #15	1	33.3	5.7	6.7	100%
Mix #16	1	50	9	9	100%
Mix #17	1	50	9	11	130%

Mix 15: Optimum mix based on the strength

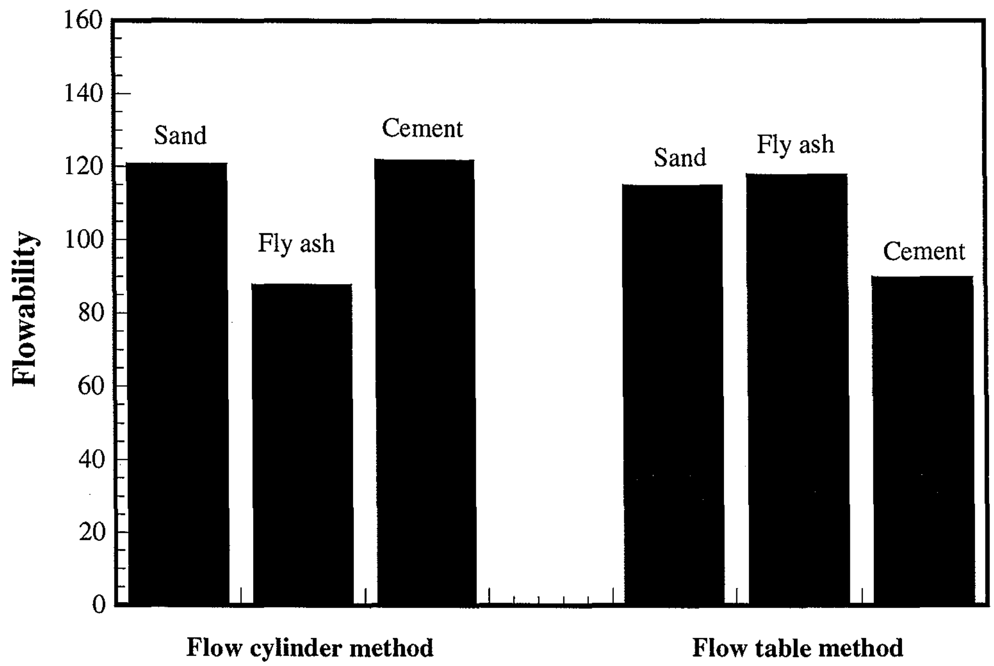


Figure 4.31. Flowability of dry materials using the Flow cylinder and Flow table tests.

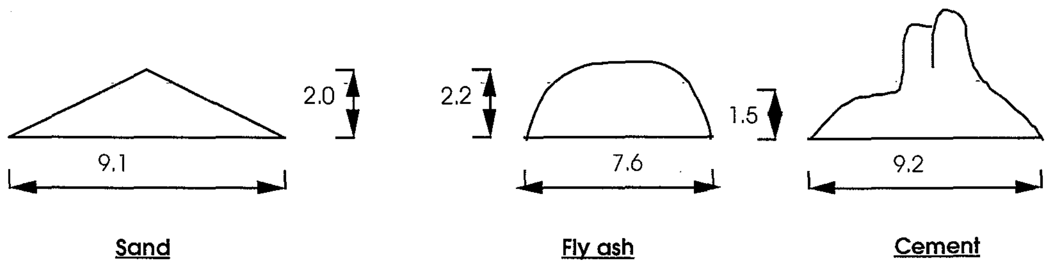


Figure 4.32 Flow shapes of different dry materials after flow cylinder test

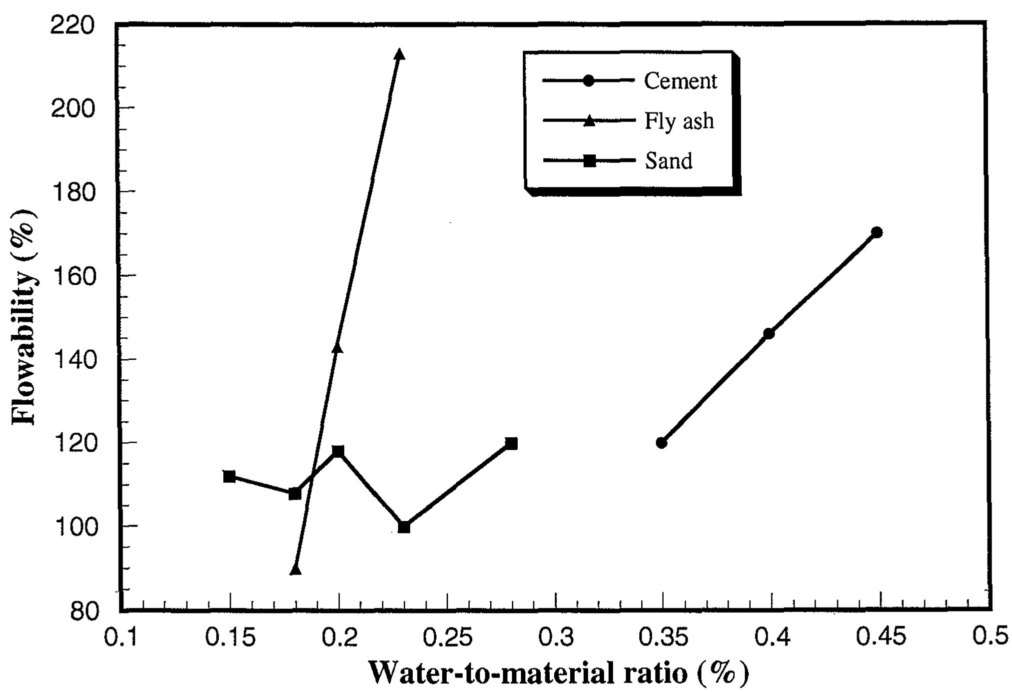


Figure 4.33 Flowability of different wet materials

4.4.3.2 Engineering properties

(a) Pulse velocity (ASTM C 597)

Variation of Pulse velocity with curing time for each mix (Batch FF-5) of flowable fill is summarized in Tables 4.11 and the variation of pulse velocity with curing time is shown in Fig 4.34. The pulse velocity of all mixtures varied between 3000 to 5600 ft/sec. Mix #15 (Batch FF-5 (FS-3)) had the highest pulse velocity compared to the other mixes. As shown in Fig. 4.34, pulse velocities of all mix increased with curing time until 7 day. For Mix #15, and #16, pulse velocity decreased slightly during the curing time of 7 to 28 days. Mix #17 had the maximum change of pulse velocity during the curing time between 7 and 28 days. For Mix #17, the 7 day average pulse velocity of 3050 ft/sec increased by 19% to 3625 ft/sec after 28 days of curing.

(b) Unconfined compressive strength and modulus (ASTM D 2166)

The results of unconfined compressive strength with time are summarized in Table 4.11 and shown in Fig. 4.35. The unconfined compressive strength of all mixtures varied between 25 to 173 psi. Mix #15 (Batch FF-5 (FS-3)) had the highest unconfined compressive strength compared to the other mixes. As shown in Fig. 4.35, unconfined compressive strength increased with curing time. Mix #16 had the maximum change of unconfined compressive strength during the curing time between 7 and 28 days. For Mix #16, the 7 day average unconfined compressive strength of 41 psi increased by 46% to 60 psi after 28 days of curing. Unconfined compressive strength was linearly related to the pulse velocity for the flowable fill (Fig.4.37). Variation of modulus with curing time is shown in Fig. 4.36, where Mix #15 had the highest modulus.

4.4.3.3 Summary

Total of 30 laboratory tests were performed to evaluate FS-cement-fly ash flowable fill. Total of 6 flowability, 12 pulse velocity, and 12 unconfined compressive strength tests were performed to determine the workability and mechanical properties. Based on the experimental results, the following can be advanced:

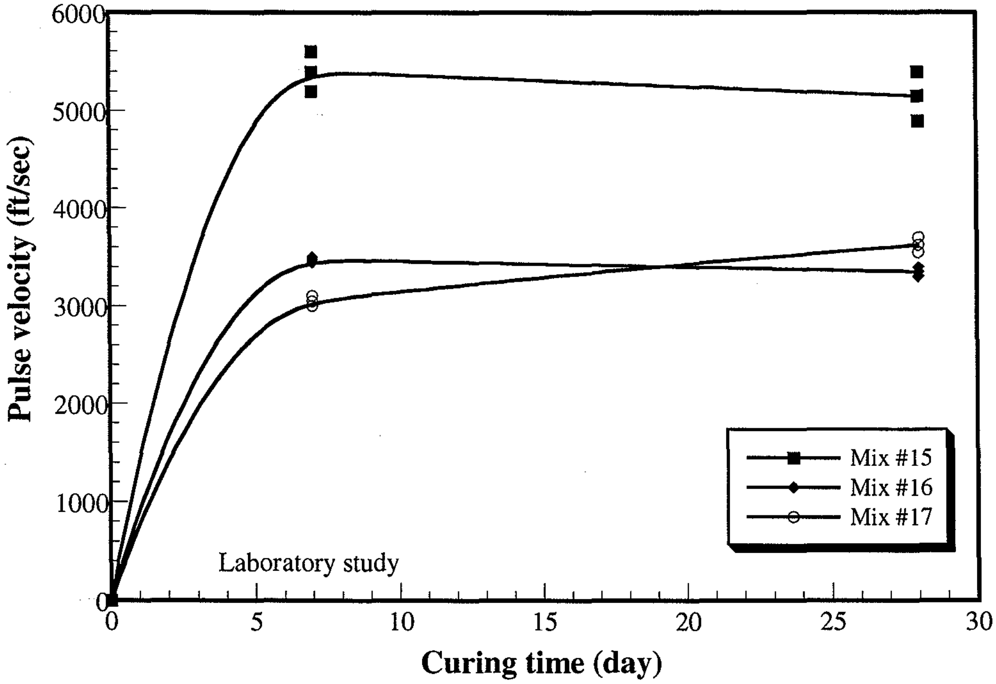


Figure 4.34 Variation of pulse velocity with curing time

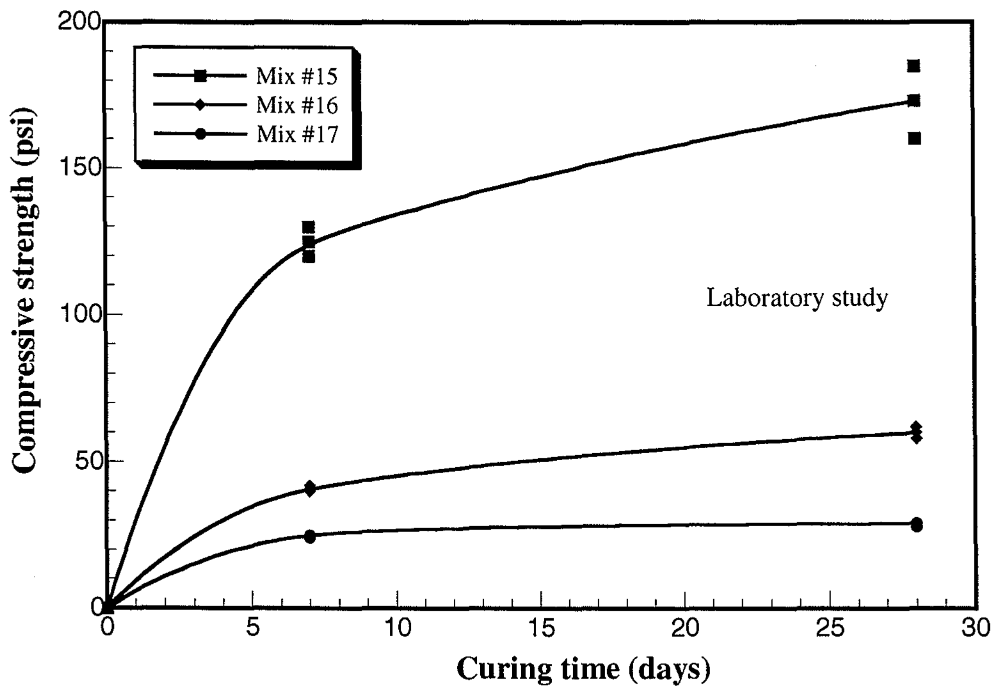


Figure 4.35 Variation of compressive strength with curing time

Table 4.11 Engineering properties of FS-cement-fly ash flowable fill

Batch FF-5 (FS-3)		Curing time	
		7-day	28-day
Mix #15 C:FS:F: W =1:33.3:5.7:6.7	Pulse velocity (ft/sec)	#1 : 5600 #2 : 5200 Aver : 5400	#1 : 5400 #2 : 4900 Aver : 5150
	Compressive strength (psi)	#1 : 120 #2 : 130 Aver : 125	#1 : 160 #2 : 185 Aver : 173
	Tangent modulus (ksi)	#1 : 39.5 #2 : 60.0 Aver : 49.8	#1 : 79.0 #2 : 80.0 Aver : 79.5
Mix #16 C:FS:F:W =1:50:9:9	Pulse velocity (ft/sec)	#1 : 3500 #2 : 3450 Aver3475	#1 : 3400 #2 : 3300 Aver: 3350
	Compressive strength (psi)	#1 : 40 #2 : 42 Aver :41	#1 :58 #2 : 62 Aver :60:
	Tangent modulus (ksi)	#1 : 20 #2 : 5 Aver : 13.5	#1 : 20.0 #2 : 19.0 Aver : 19.5
Mix #17 C:FS:F:W =1:50:9:11	Pulse velocity (ft/sec)	#1 : 3000 #2 : 3100 Aver :3050	#1 : 3700 #2 : 3550 Aver :3625
	Compressive strength (psi)	#1 : 24 #2 : 25 Aver :25	#1 : 28 #2 : 29 Aver :29
	Tangent modulus (ksi)	#1 : 6.0 #2 : 6.1 Aver : 6.1	#1 : 19 #2 : 18.8 Aver : 18.9

C: Cement
FS: Foundry Sand
F: Fly ash (Class F)
W: Water

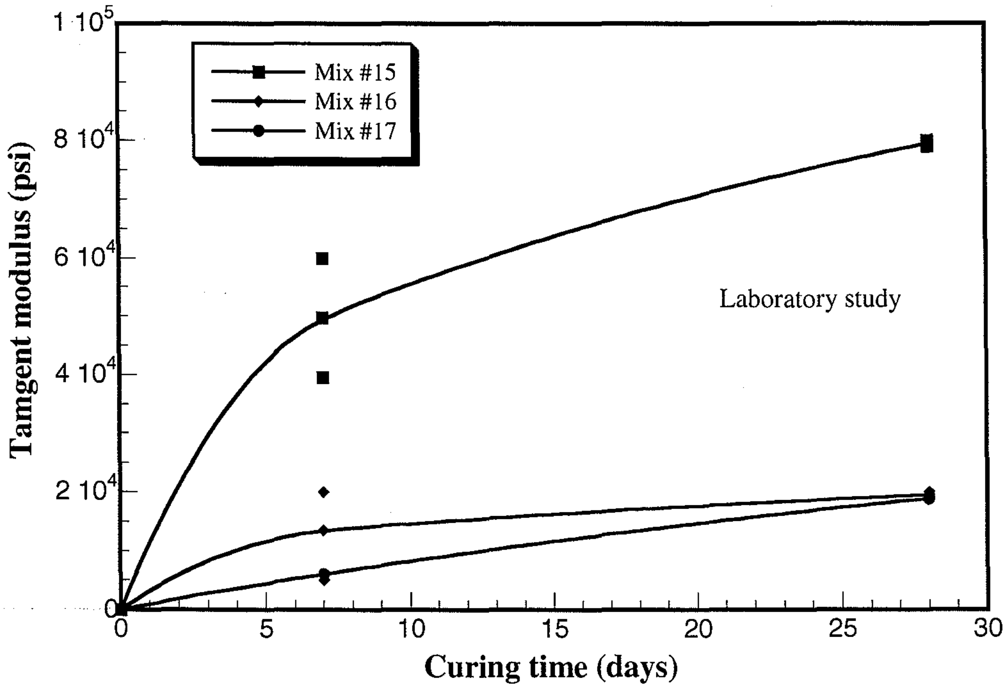


Figure 4.36 Variation of modulus with curing time

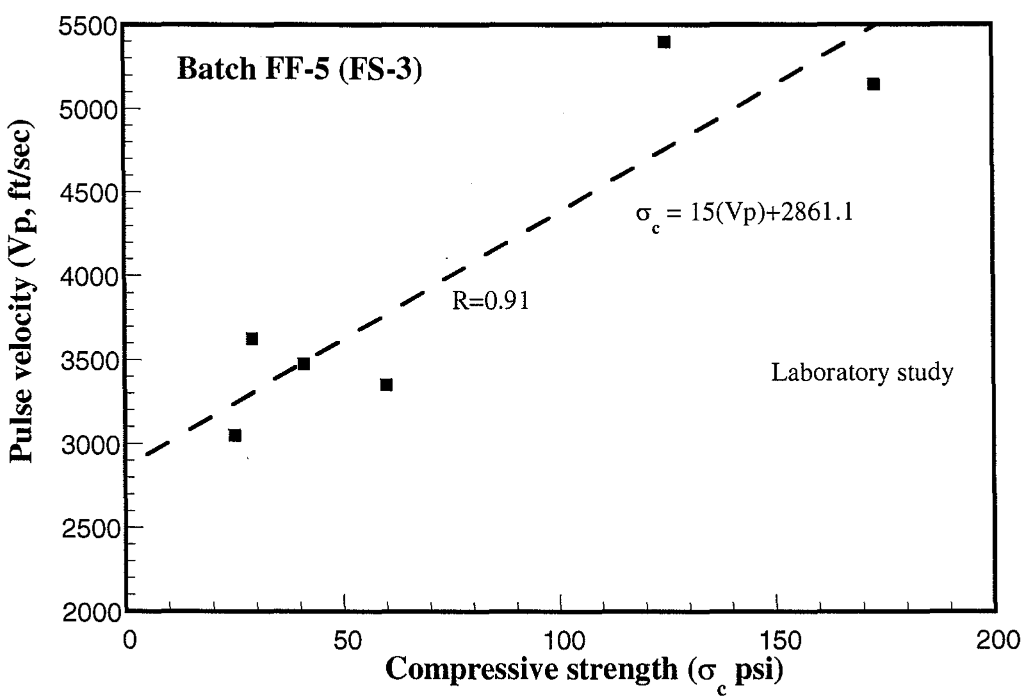


Figure 4.37 Relationship between compressive strength and pulse velocity

(1) Flowability: cement and fly ash were sensitive to the type of flowability test while the sand was not.

(2) Pulse velocity: pulse velocity of the FS-cement-fly ash flowable fill increased with curing time at varying rates. Mix #15 (Batch FF-5 (FS-3)) had the highest pulse velocity compared to the other mixes. For Mix #15, and #16, pulse velocity decreased slightly during the curing time of 7 to 28 days.

(3) Strength: The compressive strength of the FS-cement-fly ash flowable fill increased with curing time at varying rates. Mix #15 was the optimum mix based on the strength.

(4) Property Relationships: Compressive strength was linearly related to the pulse velocity for the flowable fill.

4.5 FIELD STUDY

Field samples (FS-9 flowable fill) were collected on December 21, 2000 in the Brownwood Distinct (Fig. 4.38 through 4.41), Texas where a demonstration project was undertaken to evaluate the flowable fill in the field (Coordinated by Mr. Walter Neaves). The field samples were received at UH-CIGMAT Laboratory on February 23, 2001 to characterize the performance of field samples. Total of 11 samples were received and these samples (diameter:4 inch, Height:8 inch) were cured in the plastic mold before testing as shown in Fig. 4.42. Laboratory samples were also made using FS-9 sand (Mix #1 through #7, Mix #18) to compare the engineering properties of field samples and laboratory samples. Flowability, unit weight, pulse velocity, and unconfined compressive strength tests were performed to evaluate the engineering properties of the field and laboratory samples.

4.5.1 Working property

(a) Flowability

As shown in Fig 4.43, Flowability tests were performed in the laboratory with FS cement mix #18 which was made as same Mix ratio as field Mix #19 to evaluate it's flowability. Flow cylinder (ASTM D 6103) test was performed and the flowablility was only 5%.

Table 4.12 The different mixture proportion of FS-cement flowable fill (Batch FF-6)

Batch # (FS)	Mix Number	Mix ratio (by weight)			Remarks
		Cement	FS	Water	
FF-6 (FS-9)	18	1	5.9	2.7	Laboratory sample Cylindrical (Dia:3 in, Height: 6 in)
	19	1	5.9	2.7	Field sample Cylindrical (Dia:4 in, Height: 8 in)

4.5.2 Engineering properties

(a) Unit weight

The variation of unit weight with curing time for Mix #18 and #19 are summarized in Tables 4.13 and 4.14 respectively. The variations of unit weights with the curing time are also shown in Figs 4.44. The unit weights of all the laboratory samples were higher than that of field samples as shown in Fig. 4.45. The average ratio of field to laboratory unit weight (Field unit weight / laboratory unit weight) was 0.89, with a standard deviation of 0.01 and C.O.V (coefficient of variation) of 0.0001.

(b) Pulse velocity:

The variation of pulse velocity with curing time for Mix #18 and M #19 are also summarized in Tables 4.13 and 4.14. The variation of pulse velocity with curing time is shown in Figs 4.46. The pulse velocity of laboratory sample was higher than that of field samples as shown in Fig. 4.47. The average ratio of field to laboratory pulse velocity was 0.52, with a standard deviation of 0.36 and C.O.V of 0.69. The average ratio of field to laboratory pulse velocity increased with curing time.

(c) Unconfined compressive strength:

The variation of compressive strength with curing time for mix #18 (laboratory sample) and mix #19 (field sample) are summarized in Tables 4.13 and 4.14. The variation of compressive strength with the curing time is shown in Figs 4.48.

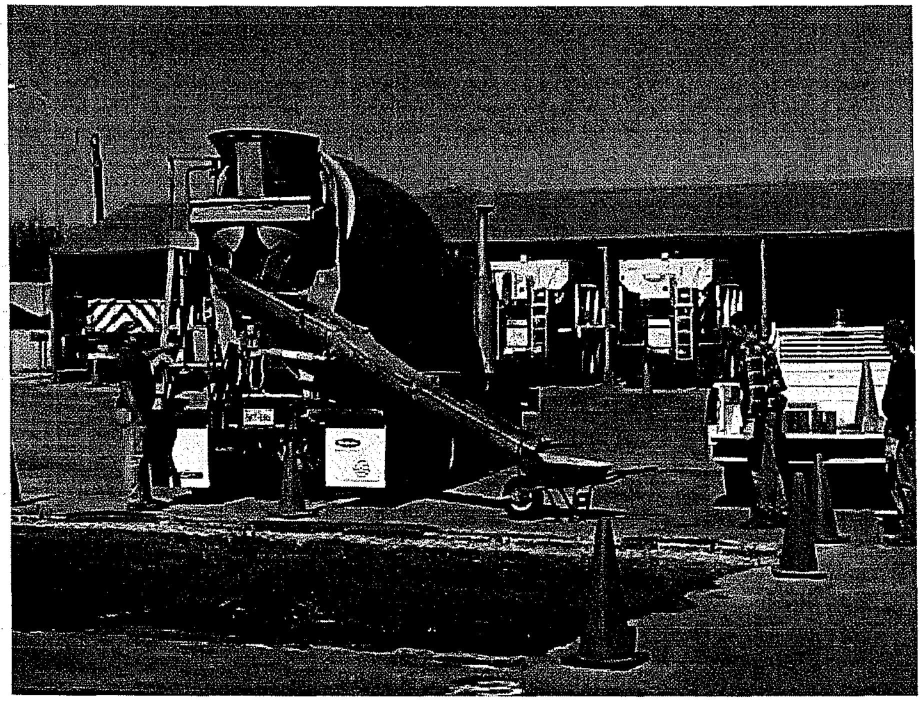


Figure 4.38 Collecting the field sample (C:FS:W = 1: 5.9:2.7) from a ready-mix truck in Brownwood, Texas

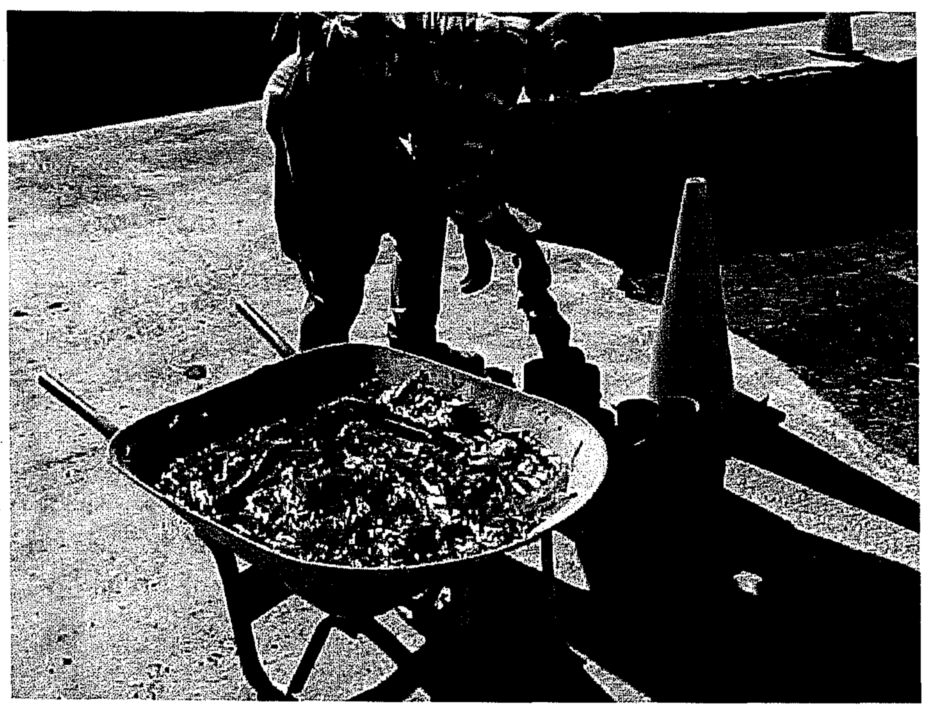


Figure 4.39 Collecting the field sample (C:FS:W = 1: 5.9:2.7) in Brownwood, Texas

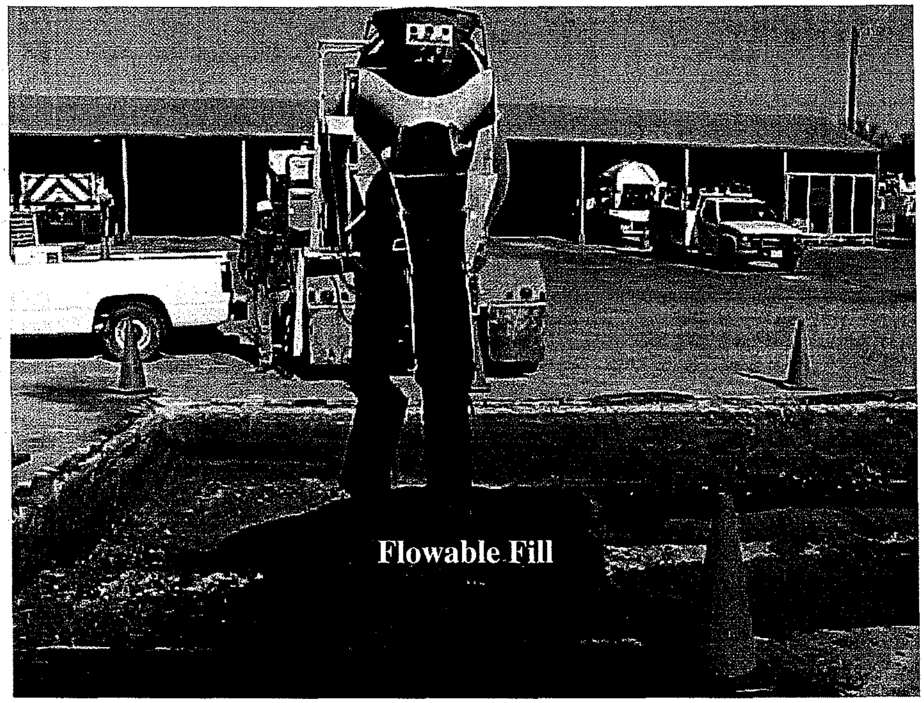


Figure 4.40 Flowable fill being discharged into the test pad in Brownwood, Texas (Additional water was added to the mix)

Figure 4.41 Closer view of the flowable fill (C:FS:W = 1: 5.9:2.7) in Brownwood, Texas (Additional water was added)

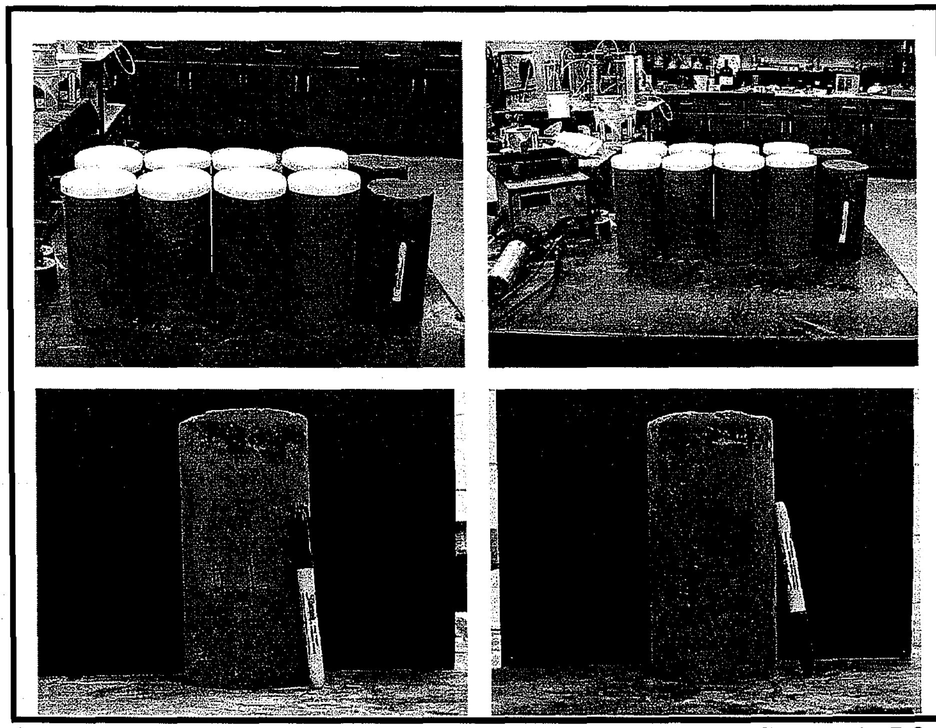


Figure 4.42 Field samples from Brownwood, Texas (C:FS:W = 1: 5.9:2.7)

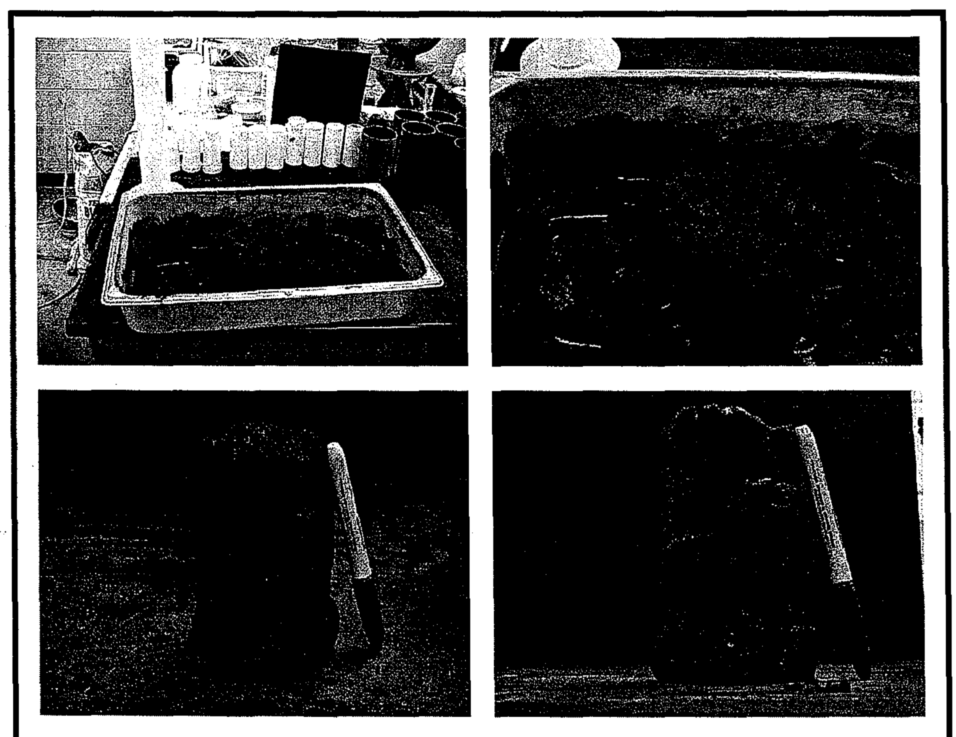


Figure 4.43 Flowability test (laboratory sample, C:FS:W = 1: 5.9:2.7)

Table 4.13 Engineering properties of Batch FF-6 (FS-9a, laboratory sample)

Batch FF-6 (FS-9)		Curing time		
		7- day	28-day	180-day
Mix #18 Laboratory sample	Unit weight (lb/ft^3)	101.7	100	97.1
	Pulse velocity (ft/sec)	5494	5437	5376
	Compressive strength (psi)	#1 : 249 #2 : 286 Aver : 268	#1 : 466 #2 : 575 Aver : 521	#1 : 395 #2 : 454 Aver : 425
	Moisture content (%)	32	27	17.5

Table 4.14 Engineering properties of Batch FF-6 (field sample)

BATCH FF-6 (FS-9)		CURING TIME		
		90 day	180 day	365 day
Mix #19 Field sample	Unit weight (lb/ft^3)	86.8	87	87.8
	Pulse velocity (ft/sec)	3772	5000	5168
	Compressive strength (psi)	#1 : 350 #2 : 367 Aver : 359	#1 : 310 #2 : 350 Aver : 330	#1 : 270 #2 : 394 Aver : 332
	Moisture content (%)	40	37	36

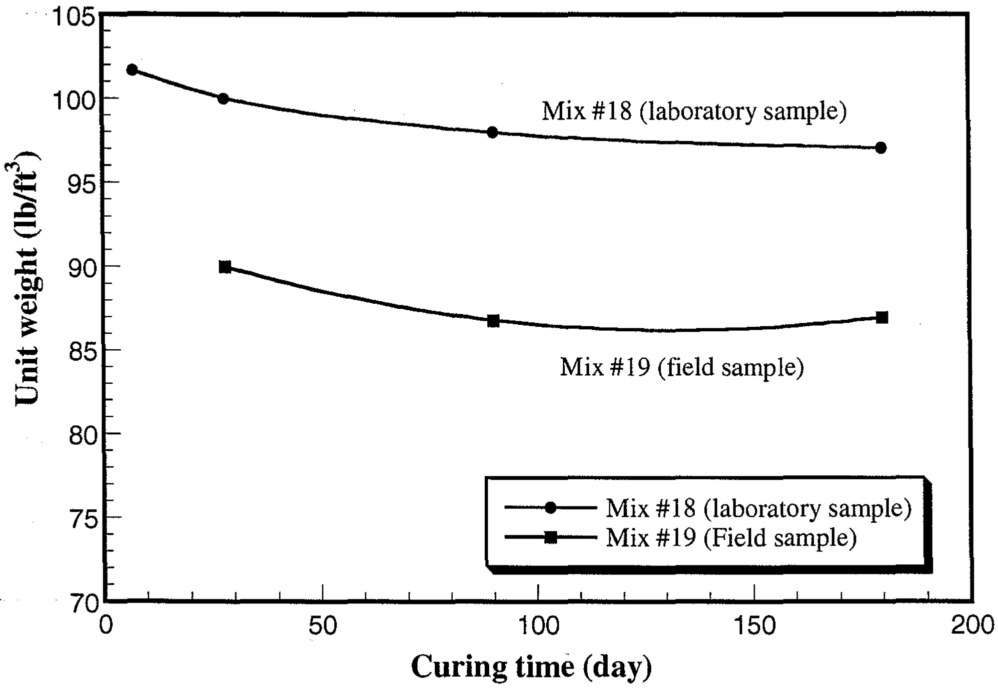


Figure 4.44 Variation of unit weight with curing time (laboratory and field sample)

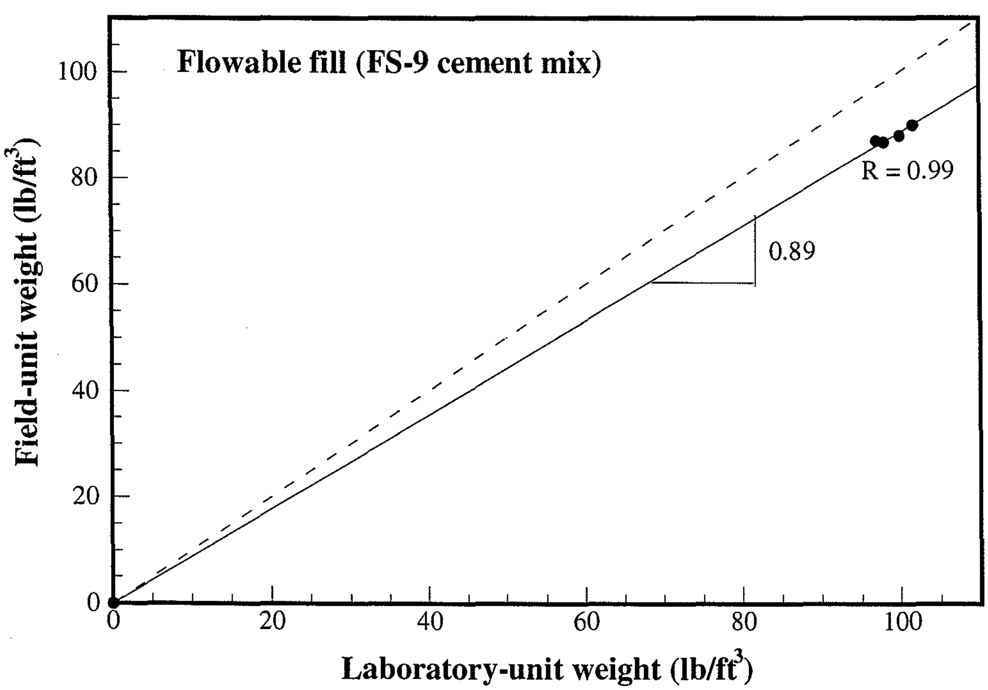


Figure 4.45 Comparison of unit weight (laboratory and field sample)

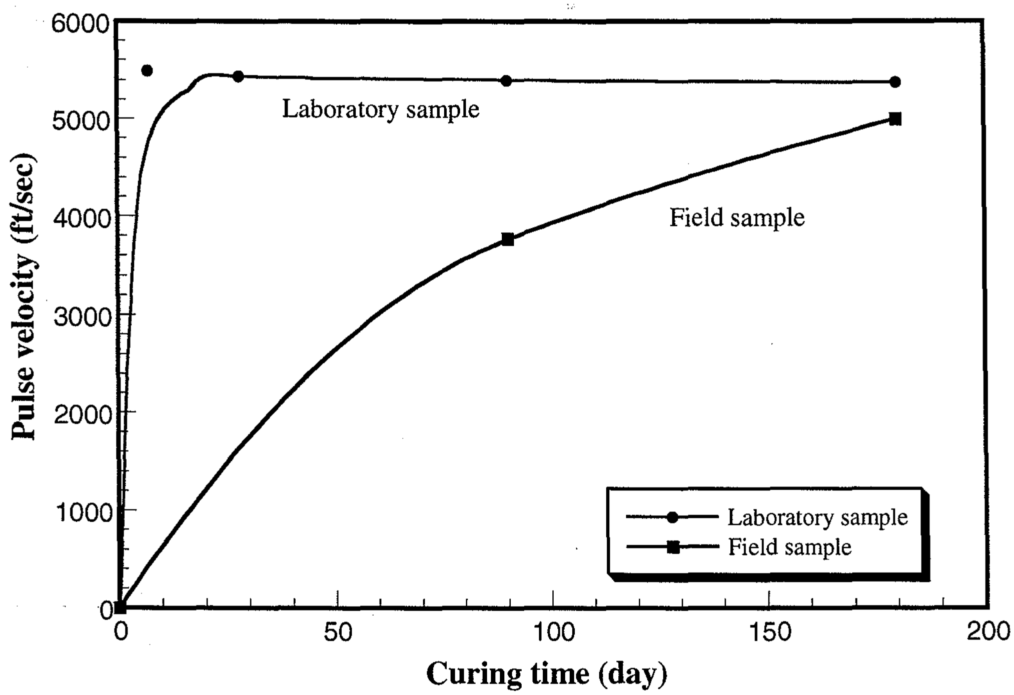


Figure 4.46 Variation of pulse velocity with curing time (laboratory and field sample)

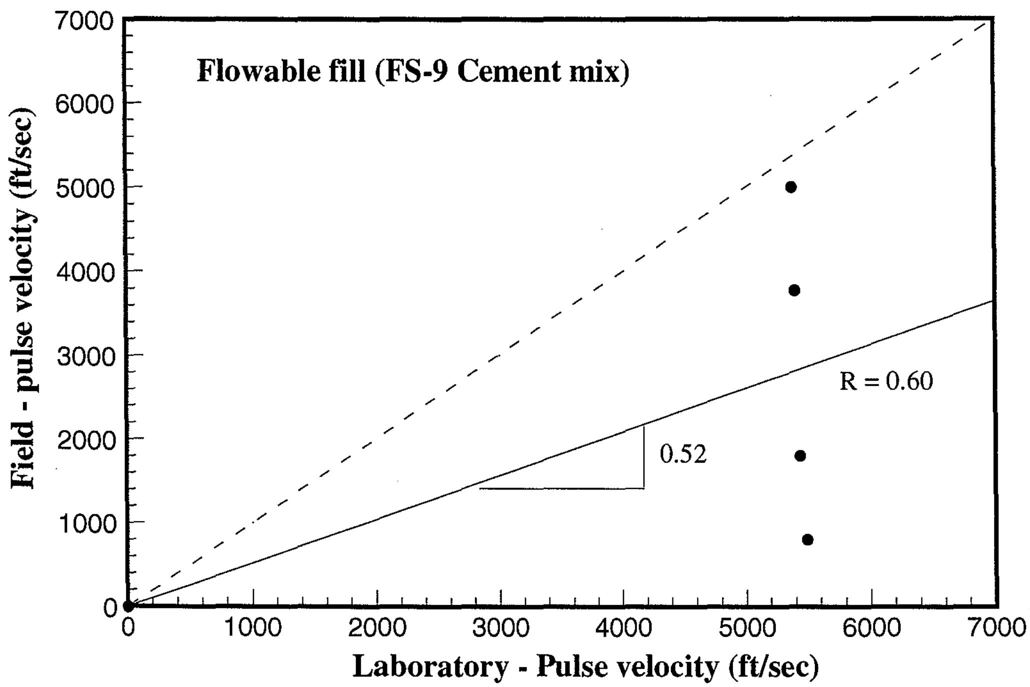


Figure 4.47 Comparison of pulse velocity (Laboratory and Field sample)

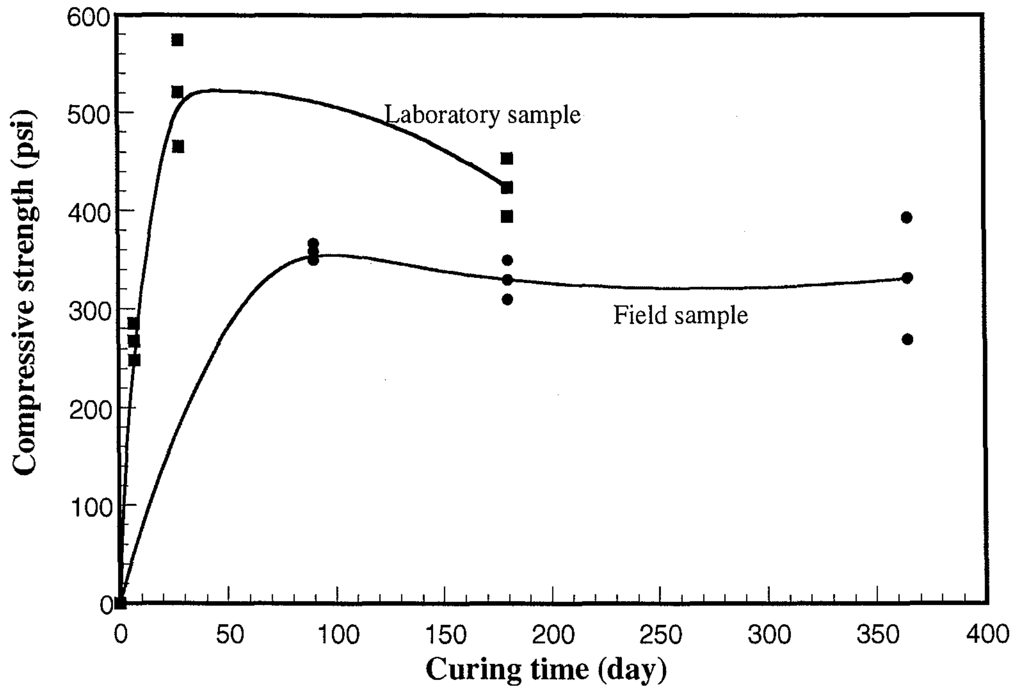


Figure 4.48 Variation of compressive strength with curing time (laboratory and field sample)

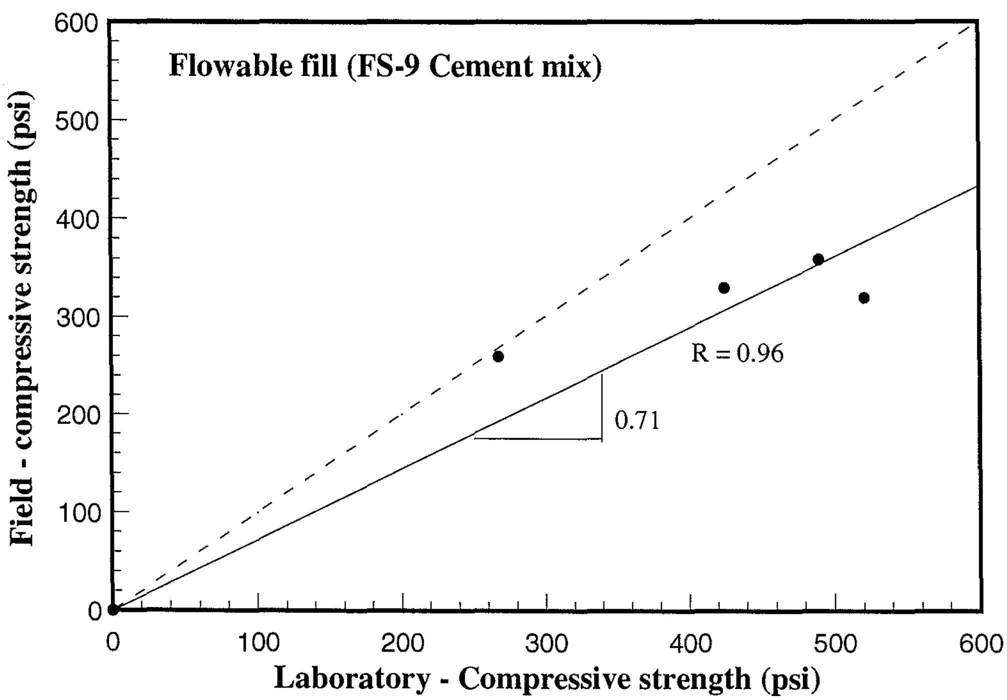


Figure 4.49 Comparison of compressive strength (laboratory and field sample)

The compressive strengths of all laboratory samples were higher than that of Field samples as shown in Fig. 4.49. The average ratio of field to laboratory unconfined compressive strength was 0.71, with a standard deviation of 0.17 and C.O.V of 0.24. The average ratio of field to laboratory compressive strength also increased with curing time.

4.5.3 Summary

Total of 6 field samples (Brownwood, Texas) have been tested. Laboratory samples were made using the same foundry sand (FS-9). Based on the test results, following can be concluded:

(1) Unit weight: The unit weight all the laboratory samples were higher than that of field samples as shown in Fig. 4.45. The average ratio of field to laboratory unit weight (Field unit weight / laboratory unit weight) was 0.89, with a standard deviation of 0.01 and C.O.V (coefficient of variation) of 0.0001.

(2) Pulse velocity: The pulse velocity of laboratory sample was higher than that of field samples. The average ratio of field to laboratory pulse velocity was 0.52, with a standard deviation of 0.36 and C.O.V of 0.69. The average ratio of field to laboratory pulse velocity increased with curing time.

(3) Unconfined compressive strength: The compressive strengths of all laboratory samples were higher than that of Field samples. The average ratio of field to laboratory unconfined compressive strength was 0.71, with a standard deviation of 0.17 and C.O.V of 0.24. The average ratio of field to laboratory compressive strength also increased with curing time.

4.6 ANALYSIS OF FLOWABLE FILL

Total of 116 laboratory samples and 6 field samples have been tested as summarized in Table 4.15 to determine the unit weight, pulse velocity, and unconfined compressive strength of the mixes. Total of 119 flowability tests were performed to evaluate the flowability of the mixes. Test results were used to investigate the property relationships for the flowable fill mixes.

4.6.1 Water-to-cement Ratio

The water-to-cement ratio was varied from 2.5 to 11 with an average of 6.0. Variation of water-to-cement is presented in Fig. 4.50 and compared to the information in the literature where the water-to-cement ratio varied form 3 to 15.

4.6.2 Compressive strength

The 28 day compressive strength of mixes varied from 27 to 521 psi. The average of strength was 130 psi. The compressive strength was less than 100 psi for 63% of the specimens. The distributions of the data are shown in Fig. 4.51. The compressive strengths of 44 % mixes were between 50 to 100 psi. About 16% of the specimens had strength over 200 psi.

4.6.3. Compressive strength versus water-to cement ratio

The variations of compressive strengths cured for 28 days with water-to-cement ratio is compared to the literature data in Fig. 4.52. The relationship is non-linear and the laboratory test results were lower in strength compared to literature values for comparable to water-to-cement ratio.

4.6.4 Compressive strength versus pulse velocity relationship

The variation of pulse velocity (V_p) of mixes with the compressive strength (σ_c) is shown in Figure 4.53. The compressive strength increased linearly with increased pulse velocity. The linear relationship between compressive strength and pulse velocity was represented as (Fig. 4.53)

$$\sigma_c = 0.088(V_p) - 87 \qquad (4.6)$$

4.6.5 Compressive strength versus unit weight relationship

The unit weight of the laboratory samples varied from 71 to 101 pcf with the average value of 87 pcf. The variation of unit weight with the compressive strength (σ_c) is shown in Fig. 4.54. There was no direct relationship between compressive strength and unit weight of the flowable fill mixes.

Table 4. 15 Summary of tests performed on the laboratory and field samples

Test	Laboratory test			Field test
	FS-Cement	FS-Kaolinite-Cement	FS-Fly ash-Cement	FS-Cement
Flowability	70	28	21	None
Unit weight	80	None	12	6
Pulse velocity	80	None	12	6
Compressive strength	80	24	12	6
Sum	310	52	57	18
Total	Laboratory test : 419			Field test : 18
Remarks	Total test : 437			

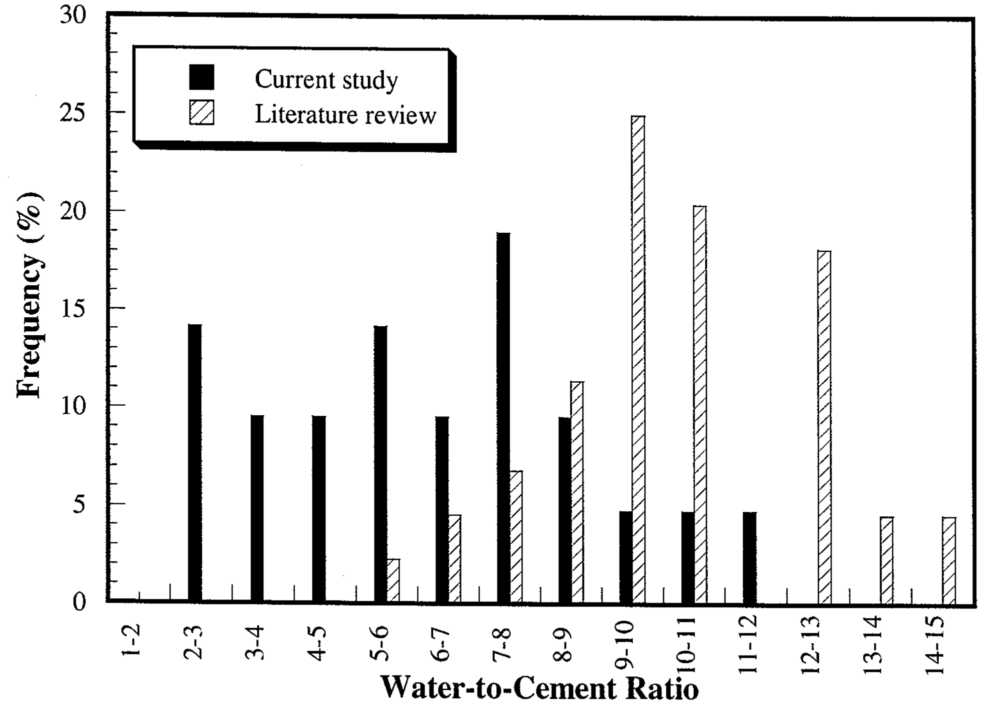


Figure 4.50 Variation of water-to-cement ratio used for flowable fill mixes

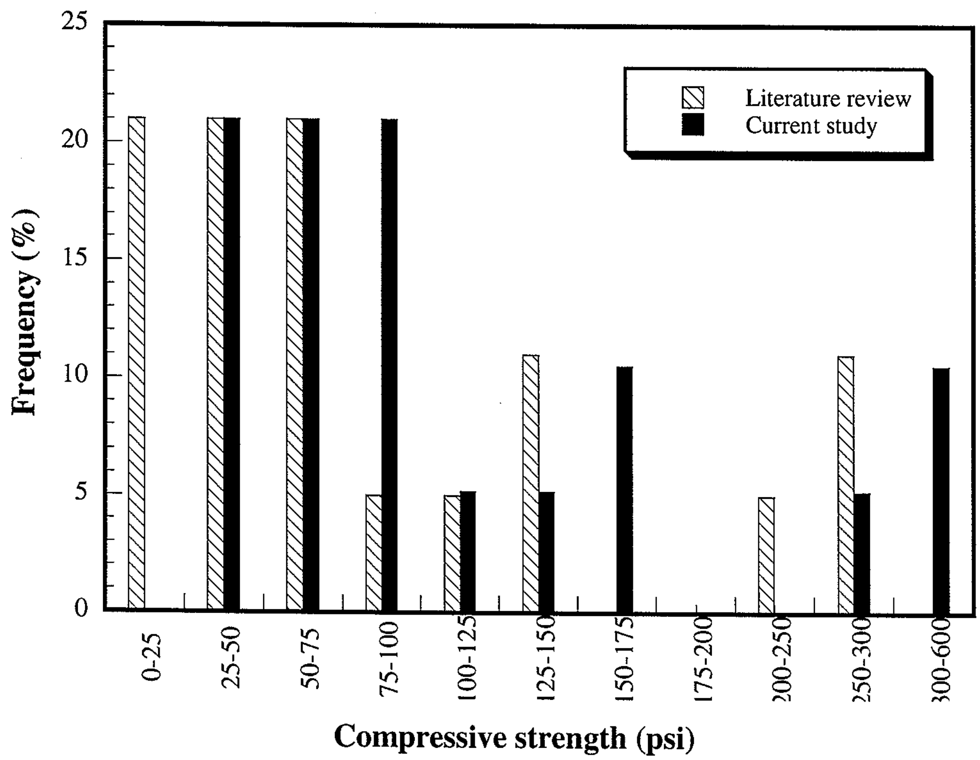


Figure 4.51 Frequency distribution of compressive strength

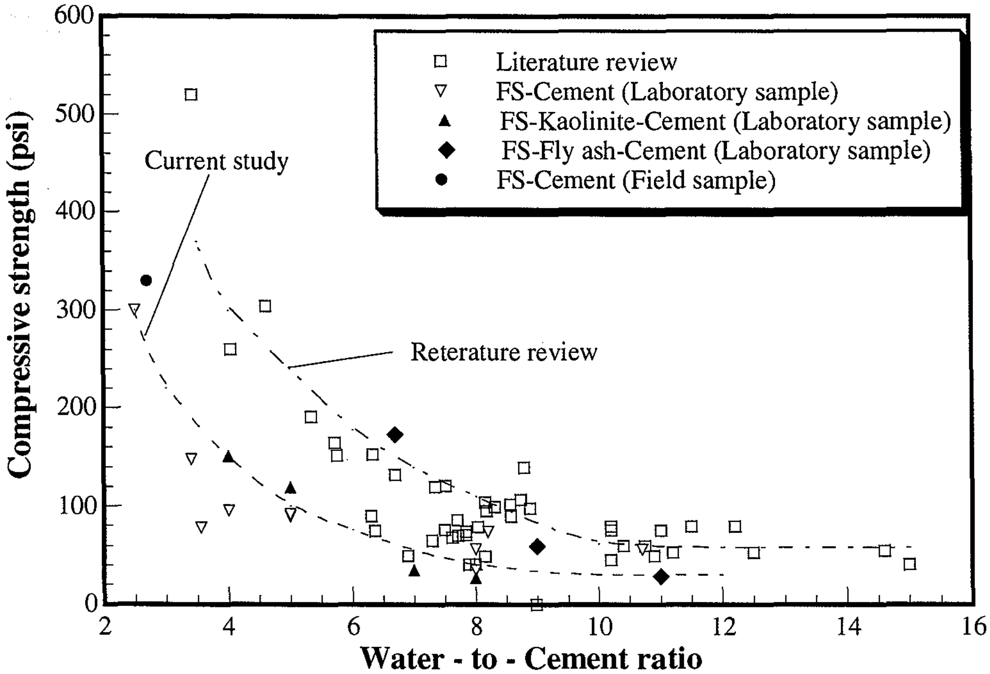


Figure 4.52 Strength versus water-to-cement ratio for FS mixes

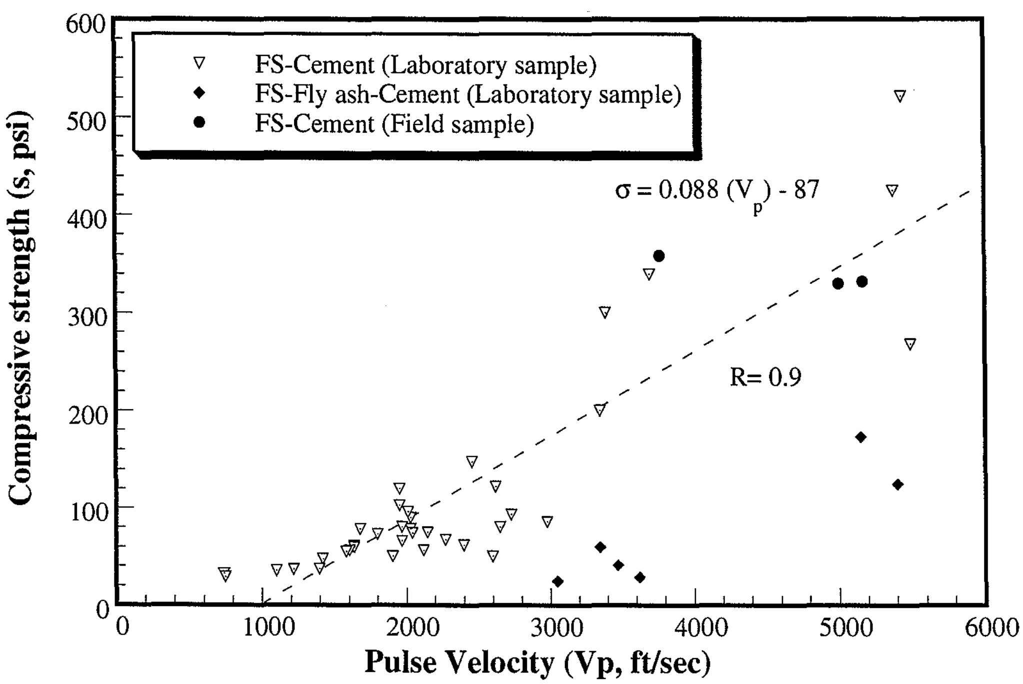


Figure 4.53 Pulse velocity versus compressive strength for flowable fill with FS

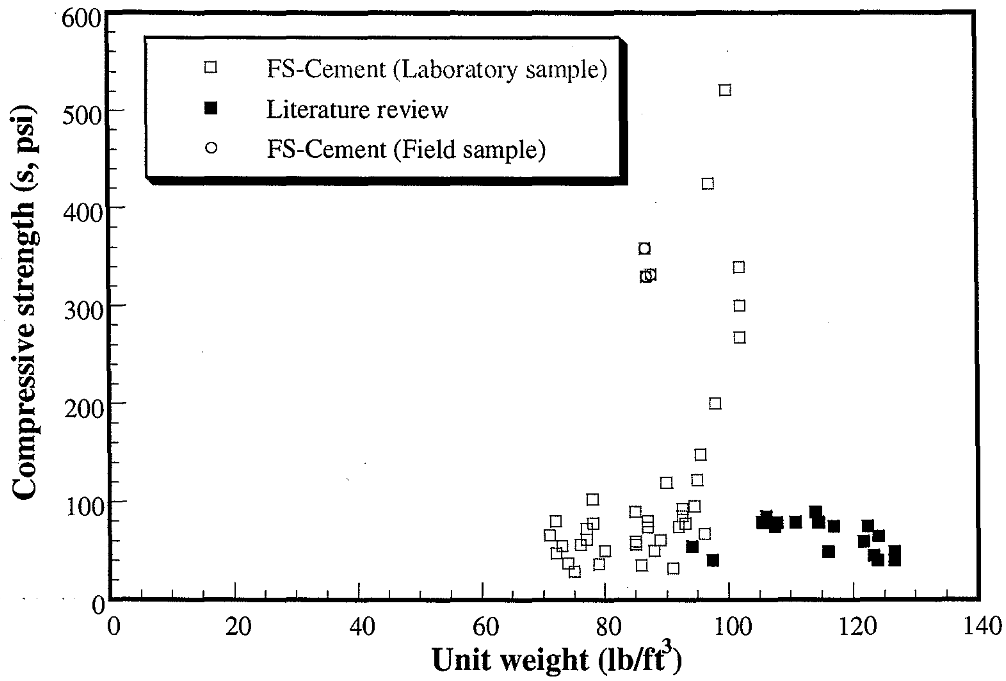


Figure 4.54 Strength versus unit weight

4.7 MODIFIED SPECIFICATION

4.7.1 Modified special specification (ITEM 4438) – Flowable backfill

1. DESCRIPTION. This Item shall govern for flowable backfill composed of portland cement, fly ash (optional), fine aggregate, water, and admixtures when required by the Engineer. Flowable backfill may be used, when shown on the plans or approved by the Engineer, as trench, hole or other cavity backfill, structural, insulating, and isolation fill, pavement bases, conduit bedding, erosion control, void filling, and other uses.

2. MATERIALS.

(1) Cement. The cement shall be either Type I or II portland cement conforming to Item 524, "Hydraulic Cement."

(2) Fly Ash. Fly Ash, when used, shall conform to the requirements of Item 421, "Portland Cement Concrete."

(3) Admixtures. Admixtures shall be added to the mix in accordance with the manufacturer's recommendations and shall be tested by the Contractor to insure they accomplish the desired effects in the mix.

(4) Fine Aggregate. The fine aggregate shall be **natural sand or foundry sand (ferrous)** that is fine enough to stay in suspension in the mortar to the extent required for proper flow. **Foundry sand should satisfy the DMS-11000 guidelines for Nonhazardous Recyclable Material (NRM).** The fine aggregate shall conform to the following gradation and plasticity index (PI) requirements.

Sieve Size	Percent Passing
3/4 inch	100
No. 200	0-30

PI shall not exceed six (6) when tested in accordance with Test Method Tex-106-A.

The fine aggregate gradation shall be tested in accordance with Test Method Tex-401-A.
(5) Mixing Water. Mixing water shall conform to the requirements of Item 421, "Portland Cement Concrete."

3. MIX DESIGN. Unless otherwise shown on the plans, the Contractor shall furnish an acceptable mix meeting the following requirements:

(1) Strength. The 28 day compressive strength range, when tested in accordance with Test Method Tex-418-A, shall be 80 psi to 150 psi, to insure efficient future excavation. Variations of the specified strength will be allowed as approved by the Engineer.

(2) Consistence. The mix shall be designated to be placed without consolidation and shall fill all intended voids. The consistency shall be tested by filling an open-ended three-inch diameter by six inches high cylinder to the top with flowable fill. The cylinder shall be immediately pulled straight up and the correct consistency of the mix shall produce a minimum of eight (8) inch diameter circular spread with no segregation.

The Contractor shall have the option of using specialty type admixtures to enhance the flowability, reduce shrinkage, and reduce segregation by maintaining solids in suspension. When shrinkage is a concern, the Engineer may require the flowable backfill to contain a shrinkage compensator or other chemical admixtures to enhance the properties of the mix. All admixtures shall be proportioned in accordance with the manufacturer's recommendations.

The flowable fill shall be mixed by central-mixed concrete plant, ready-mix concrete truck, pugmill, or other method approved by the Engineer.

4. QUALITY FLOWABLE FILL. Unless otherwise shown on the plans, the Contractor shall furnish and properly maintain all test molds. The test molds shall meet the

requirements of Test Method Tex-418-A and, in the opinion of the Engineer, must be satisfactory for use at the time of use. In addition, the Contractor shall be responsible for furnishing personnel to remove the test specimens from the molds and transport them to the proper curing location at the schedule designated by the Engineer and in accordance with the governing specification. For all concrete items the Contractor shall have a wheelbarrow, or other container acceptable to the Engineer, available to use in the sampling of the concrete. The Contractor is responsible for disposing of used, broken test specimens. A strength test is defined as the average of the breaking strength of two (2) cylinders. Each specimen will be tested in accordance with Test Method Tex-418-A.

Curing of the specimen shall be in accordance with the following. Storage conditions during the first 24 hours have an important influence on the strength developed in **flowable fill**. During the first 24 hours, all test specimens shall be stored under conditions that prevent loss of moisture and where the temperature range is 60 to 80 degrees F. Immediately after forming the cylinders, cover them with cover plates or caps, then with several thicknesses of wet burlap or wet cotton mats. Keep the covering thoroughly saturated until the cylinders are removed from the molds. For shipment to the laboratory for strength testing, wrap the cylinders carefully in wet paper, secure in wet burlap or seal in a plastic bag.

5. CONSTRUCTION METHODS. The Contractor shall submit a construction method and a plan for approval of the Engineer. The Contractor must provide a means of filling the entire void area and be able to demonstrate that this has been accomplished. This must be done without the use of a vibrator. Care shall be taken to prevent the movement of the insert structure from it's designated location. If voids are found in the fill or if any of the requirements are not met as shown on the plans, it will be the Contractor's responsibility to remove and replace or correct the problem without additional cost to the State.

6. MEASUREMENT. This Item will be measured by the cubic yard of material in place. Cubic yards will be computed on the basis of the measured area to the lines and grades

shown on the plans or as directed by the Engineer. Measurement will not include additional volume caused i by slips, slides or cave-ins resulting from the action of the elements or the Contractor's operations.

7. PAYMENT. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Flowable Backfill". This price shall be full compensation for furnishing, hauling, and placing all materials and for all tools, labor, equipment, and incidentals necessary to complete the work.

4.8 CONCLUSIONS

Tests were performed on various flowable fill mixes to evaluate the flowability and strength properties with FS, kaolinite, cement, and fly ash. Total of 116 laboratory samples and 6 field samples have been tested. The following conclusions are advanced based on the test results:

(1) Unit weights of laboratory samples were higher than that of field samples by 11 %.

(2) Pulse velocities of laboratory samples were higher than that of field samples by 48 %.

(3) Unconfined compressive strength of laboratory samples were higher than that of field samples by 30%.

(4) Flowable fill mixes can be designed with and without clay and fly ash to achieve the desired strength by varying the FS-to-cement ratio and water-to-cement ratio. FS showed minimum flowability in the water/FS ratio range of 20 to 45.

(5) Property Relationships: A liner relationship was observed between the compressive strength and pulse velocity for the flowable fill mixes investigated in this study.

(6) Strength: The compressive strength of the flowable fill increased with curing time at varying rates. Design curves have been developed (compressive strength versus cement-to-sand ratio). Superplastizer can be used to improve the strength of FS-Cement-kaolinite clay flowable fills.

(7) Some flowable fill mixes showed reduction in strength after long period of curing time.

(8) In the range of mixes tested, the compressive strength was almost independent of the unit weight.

(9) The TxDOT special Specification (ITEM 4438-Flowable Backfill), has been modified to include FS in the flowable fill

CHAPTER 5. DESIGNING CEMENTED SAND

Cemented sand is used in various backfill applications by TxDOT and large volumes of cemented sand are used in the Houston Distinct. TxDOT has specifications on cemented sand (Items 400.6 and 423.2, TxDOT Specification) and the recommended cement content is between 5 to 7 percent. The present study investigates the potential of using foundry sand in cemented sand mixes. A comprehensive experimental program was undertaken to investigate the changes in pulse velocity and unconfined compressive strength of cemented sand mixes.

5.1 LITERATURE REVIEW

Very limited information on cemented sand is available in the literature. Clough et al (1981) suggested that the nature and amount of cement, confining stress, gradation, and structure are the governing variables influencing the behavior of cemented sand. In the case of artificially cemented soils, curing conditions must also be considered. Huang et al (1998) investigated the properties of cemented sand at dry weights ranging from 76 to 121 lb/ft^3 (12 to 19 kN/m^3) and cement content was varied from 0% to 20%, and found that the strength and stiffness increased with increasing density and cement content, but the influence of the cementation decreased as the density increased. Schnaid et al (2001) determined that unconfined compression strength is a direct measurement of the degree of cementation.

5.1.1 Analysis of cemented sand

(a) Composition

Cemented sand is a mix of cement and natural sand. Clough et al (1981) used uniform sand (D_{50}, 0.75mm) in their investigation. In that study, cement was added up to 5% and the water content was varied from 8% to 16%.

(b) Unit weight

The dry unit weight of cemented sand varied from 76 to 121 lb/ft^3 (Clough et al, 2000; Huang et al, 1998; Clough et al, 2000; Schnaud et al, 2001). Naturally cemented sand have a dry unit weight ranging from 106 to 112 lb/ft^3 (Schnaud et al, 2001).

(c) Compressive strength

The 7-day compressive strength of cemented sand varied from 25 to 170 psi (Huang et al, 1998; Clough et al, 2000; Schnaud et al, 2001). Investigating the dependency of unconfined compression strength to cement content showed a linear relationship between unconfined compressive strength and cement content (Fig. 5.1).

5.1.2 Summary

Very limited data on cemented sand is available in the literature. Based on the literature review and analysis, the following can be concluded:

(1) The cement content was varied up to 20%.

(2) The water content varied from 8% to 16% of the dry weight of mix

(3) The unconfined compressive strength was linearly related to the cement content.

(4) No information is available in the literature about using FS in cemented sand.

5.2 OBJECTIVE

The overall objective is to design and evaluate cemented sand mixes using FS available in Texas. The specific objectives are (1) design and test cemented sand using FS in Texas, (2) determine the properties of field mixes, (3) compare the laboratory and field test results, (4) develop Specification to use FS in cemented sand by TxDOT.

5.3 EXPERIMENTAL PROCEDURE

Cemented sand was prepared by mixing sand, cement, and water in a floor model mixer in batches of 1 to 4 lbs. The mix was then compacted into plastic molds and allowed to cure at room temperature. Specimens were demolded before testing. The laboratory-testing program for cemented sand is similar to that used for flowable fill. The properties of the cemented sand measured were: (1) unit weight (2) specific electrical resistance (3) pulse velocity and (4) unconfined compressive strength.

5.4 LABORATORY STUDY

The feasibility of using FS in cemented sand was investigated. As summarized in Table 5.1, FS-9 and FS-10 sands were mixed with four different cement contents (4, 5, 6 and 7%) in preparing specimen for testing. The water-to-cement ratio for Batches CS-1 and CS-2 was 2. For Batch CS-3, water-to-cement ratio of 0.63 was used to simulate the field condition.

5.4.1 Unit weight

Unit weights of the Batch CS-3 cemented sand (7 % cemented sand) were measured and the variation of unit weight is summarized in Table 5.2. The unit weights varied from 107 to 129 lb/ft^3. As shown in Fig. 5.2, unit weight decreased slightly with curing time. The average 7, 28, and 180 days unit weights of cubic specimen were 114, 108, and 107 lb/ft^3 respectively. From the 7 to 28 days of curing time, unit weight of cubic specimen decreased by 5% and from the 28 to 180 days, unit weight of cubic specimen decreased by 1%. Cylindrical specimens of two different sizes were also tested. The average 7, 28, and 180 days unit weight of the cylindrical-1 specimen (Dia: 1.5inch) were 119, 129, and 119 lb/ft^3 respectively. For the cylindrical-2 specimen (Dia: 3.0inch), the average 7, 28, and 180 days unit weights were 114, 121, and 116 lb/ft^3 respectively. Unit weights increased with decreasing specimen size and volume by 5, 7, and 2% for the 7, 28, and 180 days of curing respectively.

5.4.2 Specific electrical resistivity

Specific electrical resistivity of Batch CS-1 cemented sands increased with curing time and cement content as shown in Fig. 5.3. In all cases, the specific electrical resisticity were higher than 3000 ohm-cm. For the 4% cemented sand, specific electrical resistivity on the 25 day of curing increased by 30, 90, and 100 % after 50, 180 and 330 days of curing respectively. For the 5% cemented sand, specific electrical resistivity on the 25 day of curing increased by 33, 70, and 130% after 50, 180, and 330 days of curing respectively. For the 6% cemented sand, specific electrical resistivity on the 25 day of curing increased by 5, 44, and 125% after 50, 180, and 330 days of curing respectively.

Table 5. 2 Engineering properties of Batch CS-3 (FS-10) cemented sand (Laboratory samples)

Batch CS-3 (FS-10)		Curing time		
		7-day	28-day	6-month
7% cement Cubic sample (2×2×2)	Unit weight (lb/ft^3)	#1 : 115 #2 : 112 Aver : 114	#1 : 105 #2 : 110 Aver : 108	#1 : 106 #2 : 108 Aver : 107
	Pulse velocity (ft/sec)	#1 : 6289 #2 : 6410 Aver : 6350	#1 : 6723 #2 : 6802 Aver: 6763	#1 : 6895 #2 : 6924 Aver : 6910
	Compressive strength (psi)	#1 : 195 #2 : 172 Aver : 184	#1 : 310 #2 : 343 Aver : 327	#1 : 362 #2 : 374 Aver : 368
	Elastic modulus (ksi)	190	200	250
7% cement cylindrical-1 (Dia:1.5 Height: 3)	Unit weight (lb/ft^3)	#1 : 114 #2 : 124 Aver 119	#1 : 120 #2 : 137 Aver : 129	#1 : 116 #2 : 121 Aver : 119
	Pulse velocity (ft/sec)	#1 : 5541 #2 : 5410 Aver : 5476	#1 : 6130 #2 : 6000 Aver : 6065	#1 : 6252 #2 : 6309 Aver : 6281
	Compressive strength (psi)	#1 : 182 #2 : 175 Aver : 179	#1 :210 #2 : 286 Aver : 248	#1 :215 #2 : 278 Aver : 247
	Elastic modulus (ksi)	120	180	175
7% cement cylindrical-2 (Dia:3 Height: 6)	Unit weight (lb/ft^3)	#1 : 112 #2 : 115 Aver : 114	#1 : 126 #2 : 115 Aver : 121	#1 : 114 #2 : 117 Aver : 116
	Pulse velocity (ft/sec)	#1 : 5376 #2 : 5270 Aver : 5323	#1 : 5100 #2 : 5120 Aver : 5110	#1 : 7215 #2 : 6849 Aver : 7032
	Compressive strength (psi)	#1 : 116 #2 : 135 Aver : 126	#1 : 220 #2 : 217 Aver : 219	#1 : 210 #2 : 190 Aver : 200
	Elastic modulus (ksi)	80	170	150

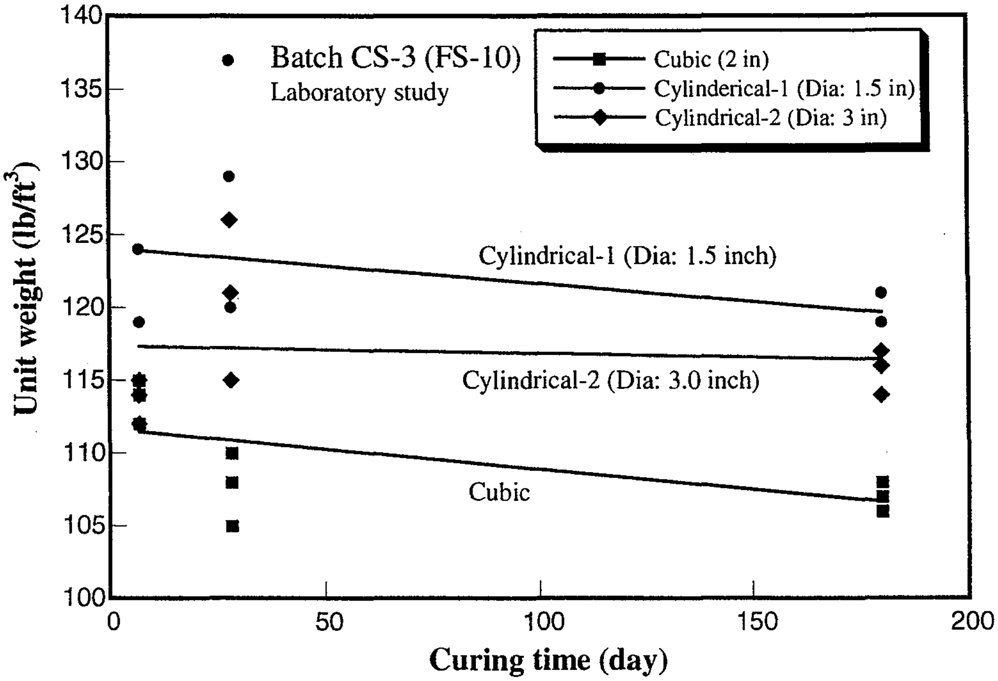


Figure 5.2 Variation of unit weight with curing time (Batch CS-3, laboratory study)

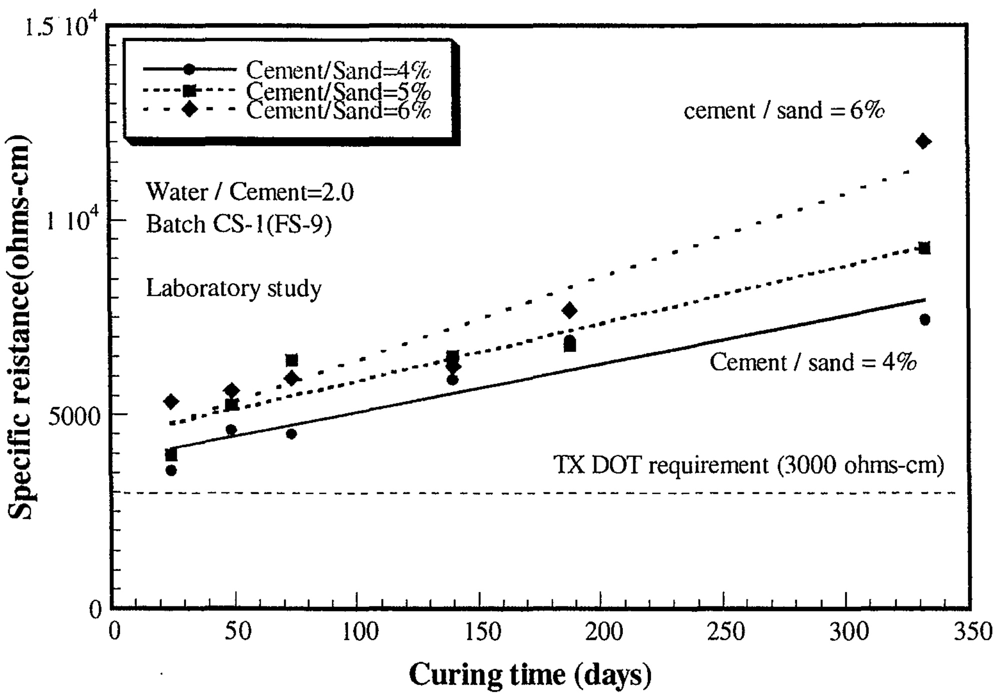


Figure 5.3 Variation of specific electrical resistivity of cemented sand with curing time and cement content (Batch CS-3, laboratory study)

As cement content increased from 4% to 6%, the specific electrical resistivity increased by 60% after 330 days of curing time.

5.4.3 Pulse velocity

Pulse velocity of the Batch CS-3 cemented sand (7% cemented sand) were measured and the variation of pulse velocity with curing time are summarized in Table 5.2. Pulse velocity varied from 5410 to 7215 ft/sec. Pulse velocity increased with curing time as shown in Fig. 5.4. The average pulse velocity of cubic, cylindrical-1 (Dia:1.5 in), and cylindrical-2 (Dia:3 in) samples after 7 days of curing was 6350, 5476, and 5323 ft/sec respectively. From the 7 to 28 days of curing time, pulse velocity of cubic sample increased by 7% to 6763 ft/sec and from the 28 to 180 day, pulse velocity of the cubic specimen increased by 2% to 6910 ft/sec. From the 7 day to 28 day curing time period, pulse velocity shows the greatest change compared with the other curing time. For the cylindrical-1 specimen (Dia: 1.5 in), pulse velocity were increased by 10% to 6065 ft/sec during the 7 day to 28 day curing time, and 4% to 6281 ft/sec during the 28 to 180 days of curing time. For the cylindrical-2 specimen (Dia:3.0 in), pulse velocity were slightly decreased by 4% to 5110 ft/sec during the 7 to 28 day curing time, and then increased 37% to 7032 ft/sec during the 28 to 180 days of curing time. As shown in Fig. 5.4, pulse velocity increased with decrease in volume of specimen.

5.4.4 Unconfined compressive strength

Unconfined compressive strength test were performed during the period of 7 day to 2 years. Unconfined compressive strengths varied from 100 to 350 psi

5.4.4.1 Batch CS-1 (FS-9) cemented sand

Variation of unconfined compressive strength with curing time and cement content is shown in Figs. 5.5, and 5.6. The Compressive strength increased with curing time and cement content. The average unconfined compressive strength varied from 114 to 350 psi. The average 7 day unconfined compressive strength of 4, 5, and 6% cemented sand were 117, 180, and 209 psi respectively.

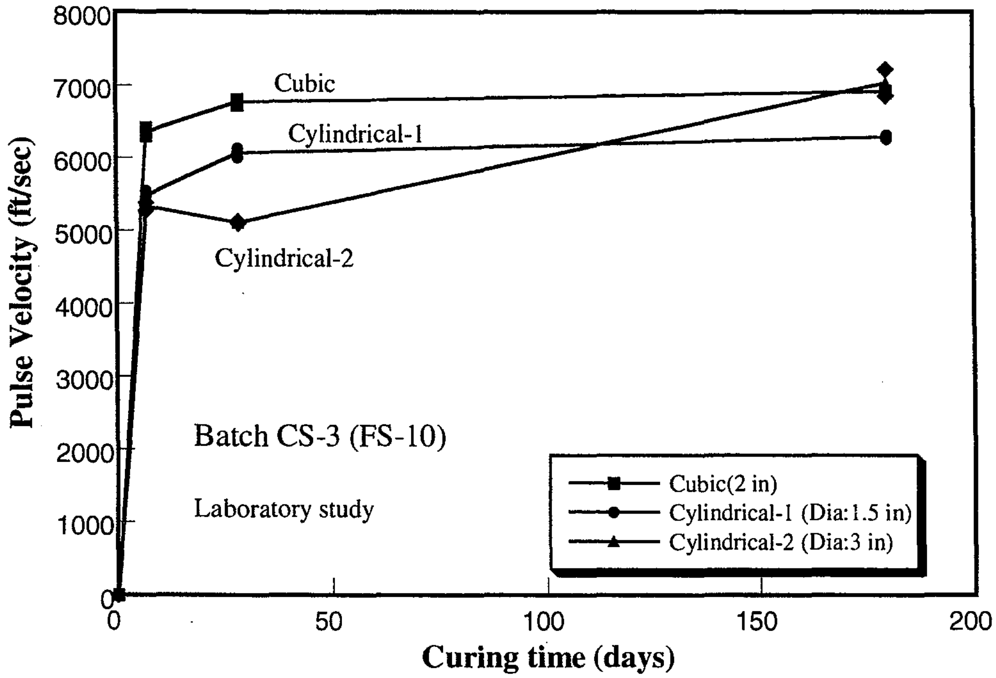


Figure 5.4 Variation of pulse velocity with curing time (Batch CS-3. laboratory study)

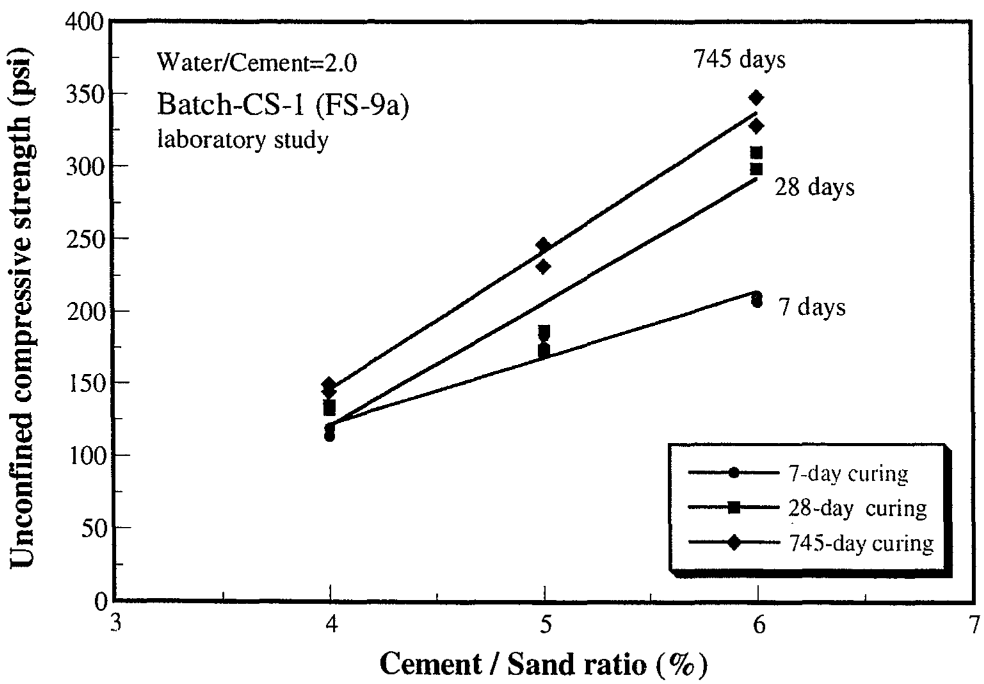


Figure 5.5 Variation of unconfined compressive strength with curing time (Batch CS-1, laboratory study)

The average 28 day unconfined compressive strength of 4, 5, and 6% cemented sand were 134, 181, and 305 psi respectively. From the 7 to 28 days of curing time, the average unconfined compressive strength of 4, 5, and 6% cemented sand increased by 15, 1 and 46 % respectively. While 4% and 5% cemented sand showed slight increase after 28 days of curing, the 6% cemented sand strength increased to 305 psi. After 2 years of curing, 4, 5, and 6% cemented sand had strengths of 148, 239, and 339 psi respectively. From 28 days to 2 years curing, the unconfined compressive strength of 4, 5, and 6% cemented sand increased by 10, 33 and 11 % respectively.

5.4.4.2 Batch CS-2 (FS-10) cemented sand

Variation of unconfined compressive strength with curing time and cement content is shown in Figs. 5.7, and 5.8. The Compressive strength increased with increasing curing time and cement content. The average unconfined compressive strength varied from 113 to 351 psi. The average 7 day unconfined compressive strength of 4, 5, and 6% cemented sand were 113, 170, and 180 psi respectively. The average 28 day unconfined compressive strength of 4, 5, and 6% cemented sand were 149, 239, and 335 psi respectively. From the 7 days to 28 days curing time, the average unconfined compressive strength of 4%, 5%, and 6% cemented sand increased by 32%, 40% and 86% respectively. After 2 years of curing, 5% cemented sand had strength of 256 psi. For 5% cemented sand, 7 day average unconfined compressive strength of 170 psi increased by 50% to 256 psi.

5.4.4.3 Batch CS-3 (FS-10) cemented sand

Variation of unconfined compressive strength with curing time is shown in Fig. 5.9, and summarized in Table 5.2. Unconfined compressive strength varied from 114 to 368 psi. The average cubic compressive strength after 7 days of curing was 184 psi. The average cylindrical-1, and cylindrical-2 compressive strengths after 7 days of curing were 179 and 126 psi. From 7 days to 28 days of curing time, the average compressive strength of cubic, cylindrical-1, and cylindrical-2 samples increased by 77, 39, and 74% respectively.

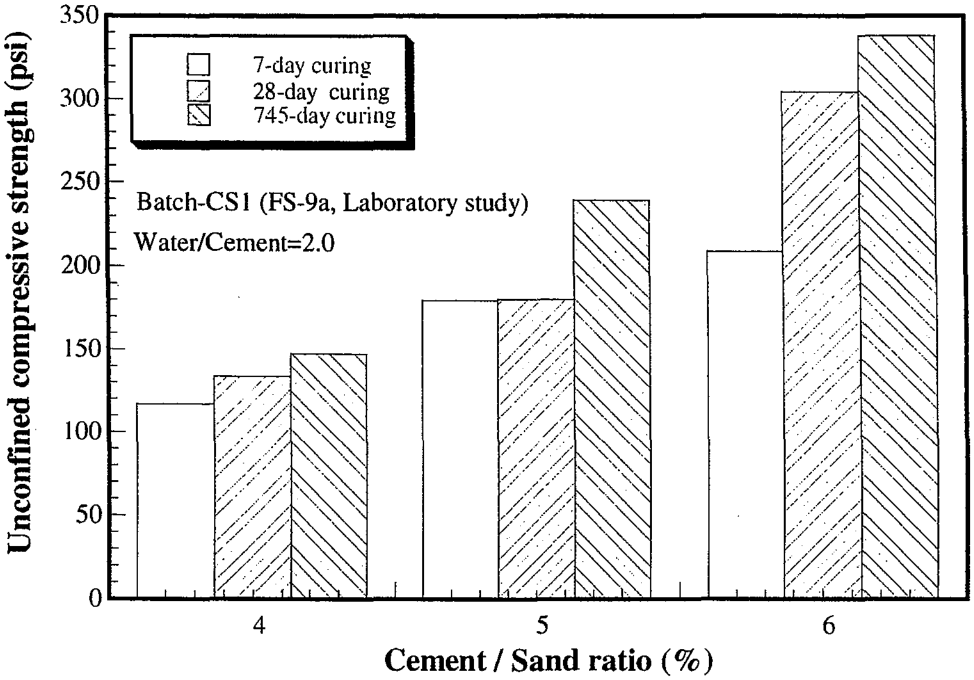


Figure 5.6 Unconfined compressive strength with varying cement / sand ratio and curing time (Batch CS-1. laboratory study)

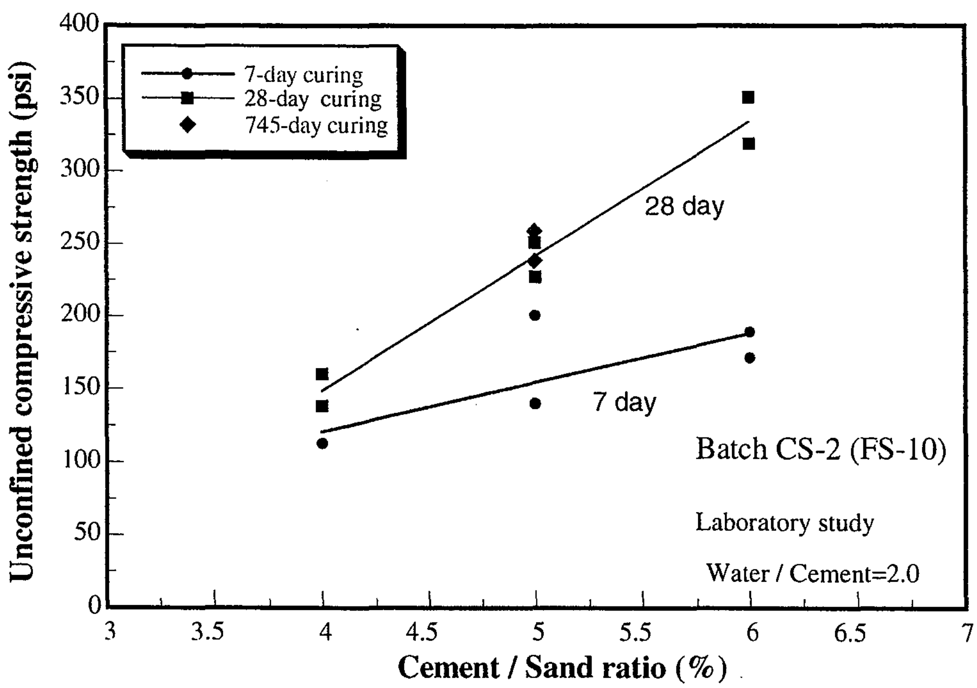


Figure 5.7 Variation of unconfined compressive strength with curing time (Batch CS-2. laboratory study)

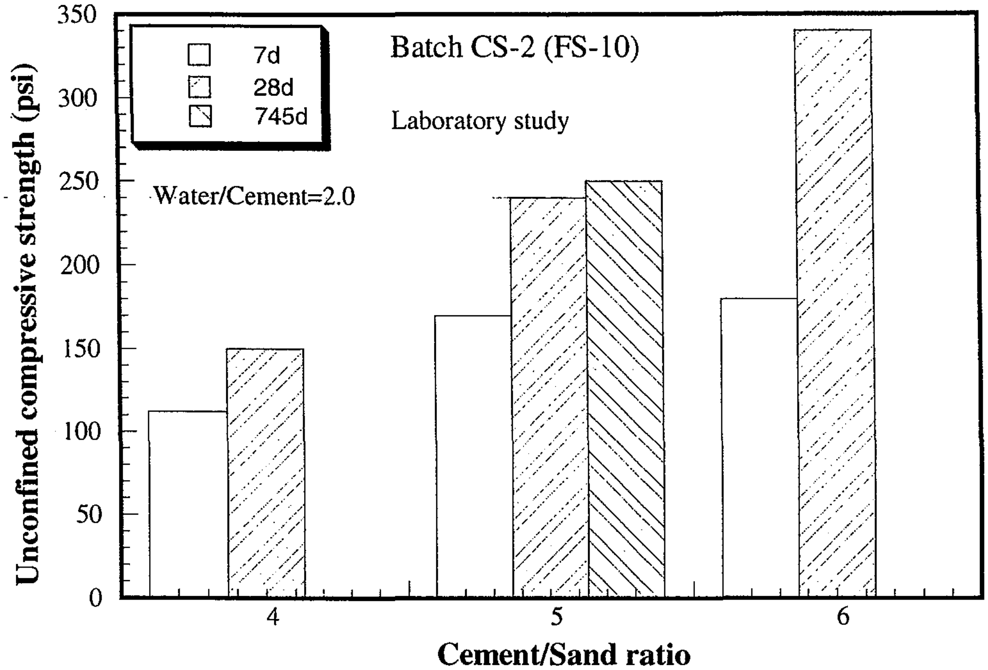


Figure 5.8 Unconfined compressive strength with varying cement / sand ratio and curing time (Batch CS-2. laboratory study)

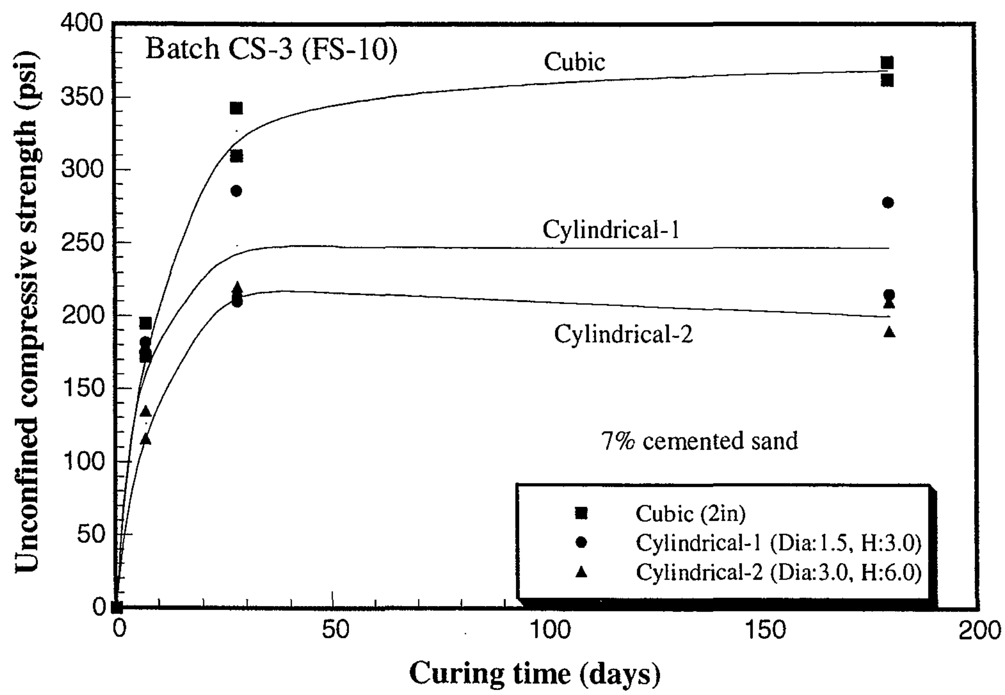


Figure 5.9 Unconfined compressive strength with varying specimen size, shape, and curing time (Batch CS-3. laboratory study)

The strength ratios, cylindrical-1-to-cubic, and cylindrical-2-to-cubic specimen strength, varied between 0.5 and 0.9 (Fig. 5.10). After 6 months of curing, cubic, cylindrical-1, and cylindrical-2 samples had a average strength of 368, 247, and 200 psi respectively. The average compressive strength of cubic sample after 6 month of curing increased by 12 % while cylindrical samples had no difference.

5.5 FIELD SAMPLES

Field samples were obtained from Site-A (7/12/01) and Site-B (7/24/01) as summarized in Table 5.3, and shown in Fig. 5.11 through Fig. 5.15(Coordinated by Mr. Thomas Lev; Tx Dot-Houston Distinct). Samples were obtained in the different shape and size molds (cubic, cylindrical). After 7, 28, and 180 days, and 1 year of curing time, unit weigh, pulse velocity, unconfined compressive strength were measured to compare the engineering properties of cemented sand.

5.5.1 Unit weight

Unit weights of two field samples (Site-A, Site-B) were measured and the variation of unit weight is summarized in Table 5.4 and 5.5. Unit weight varied from 98 to 107 lb/ft^3. The average unit weight of Site-B was higher than Site-A.

5.5.1.1 Unit weight (Site-A: US 59 S, Sugarland, Texas)

As shown in Fig. 5.16, unit weight increased slightly, with increasing the curing time. The average unit weights of Cubic specimen after 7, 28, and 180 days, and 1 year of curing, were 99, 100, 101, and 102 lb/ft^3 respectively. Cylindrical specimens that have two different size specimens were also used to the test. The average unit weights of cylindrical specimen-1 (Dia: 1.5 inch) after 7, 28, and 180 days, and 1 year of curing, were 101, 103, 103, and 103 lb/ft^3. There was no significant difference in the unit weight with curing time. The average unit weights of cylindrical specimen-2 (Dia: 3.0 inch) after 7, 28, and 180 days, and 1 year of curing were 104, 107, 108, and 107 lb/ft^3. There was also no significant difference in the unit weight with curing time.

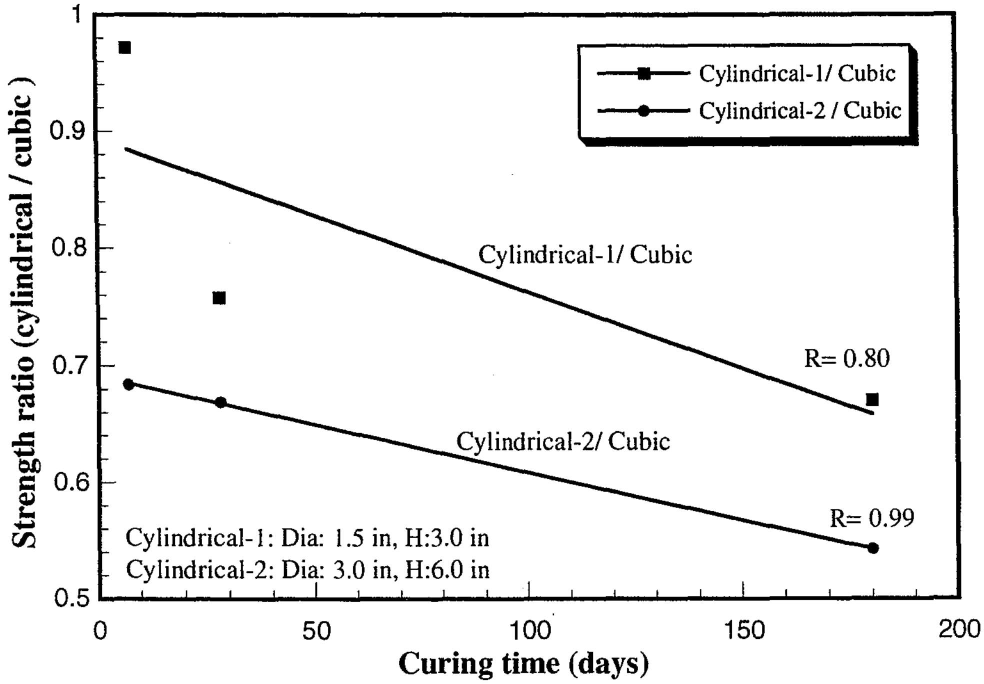


Figure 5.10 Strength ratio of cubic and cylindrical specimen (Batch CS-3. laboratory study)

Table 5.3 Field samples

Batch (FS)	Site	Cement content (%) (By weight)	Water / Cement (By weight)	Number of samples
Batch CS-4 (FS-10)	A	7	0.62	Cubic: 17 Cylindrical-1: 14 Cylindrical-2: 17
	B	7	0.62	Cubic: 0 Cylindrical-1: 14 Cylindrical-2: 13

Site A: US 59 S, Sugarland, Texas (Houston District)

Site B: Intersections of US 59 & HIGHWAY 90, Sugarland, Texas (Houston District)

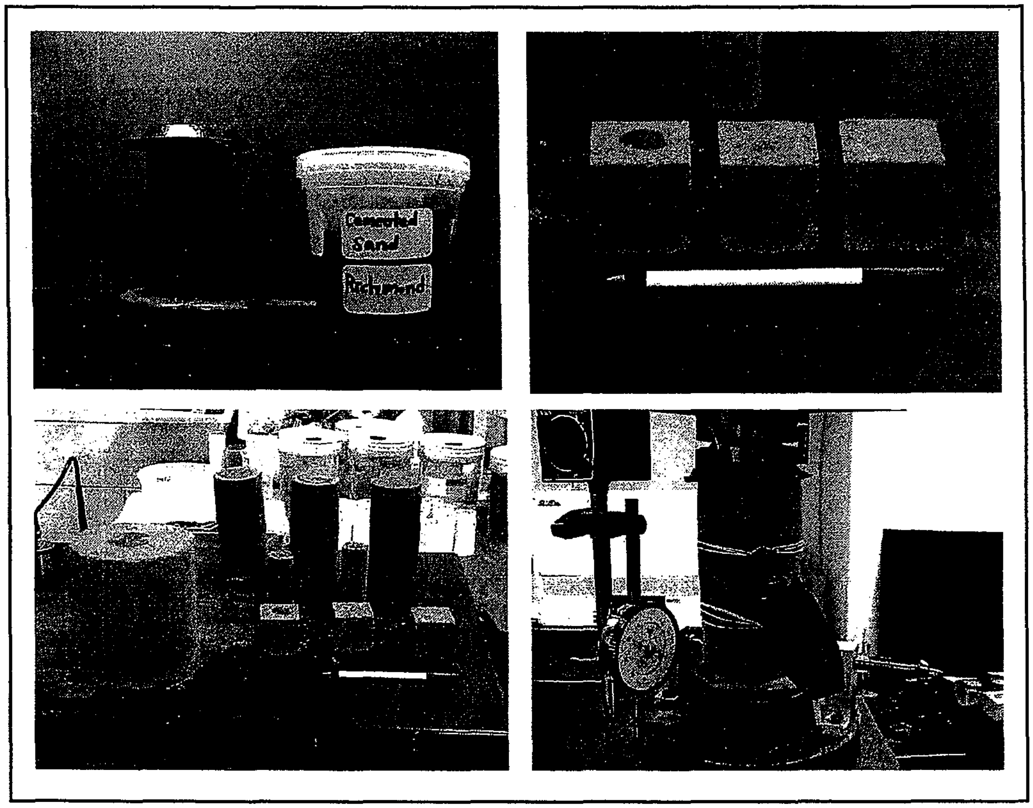


Figure 5.11 Field samples (Batch CS-4, FS-10, 7% cemented sand, Site-A)

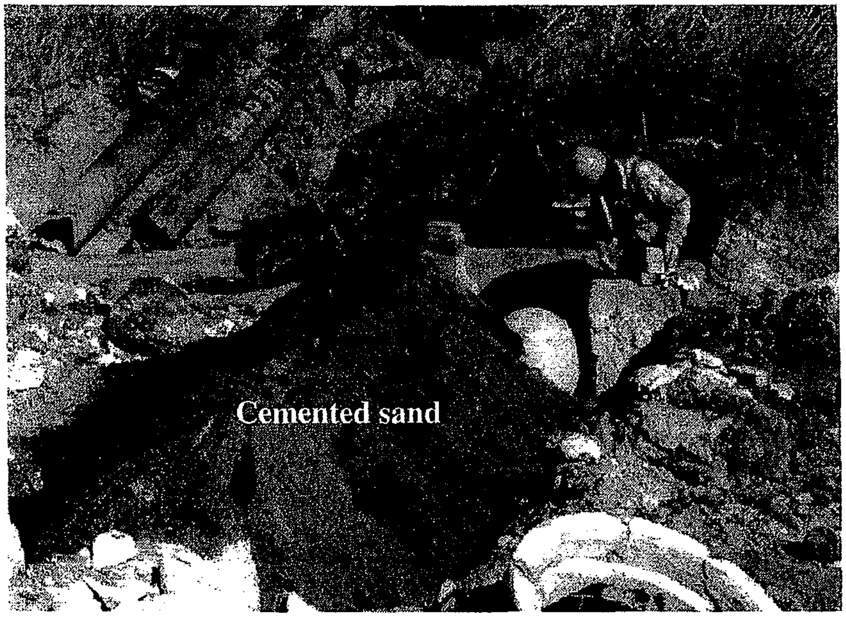


Figure 5.12 Cemented sand used as backfill for storm sewer, Sugarland, Texas (Batch CS-4, FS-10, 7% cemented sand, Site-B)

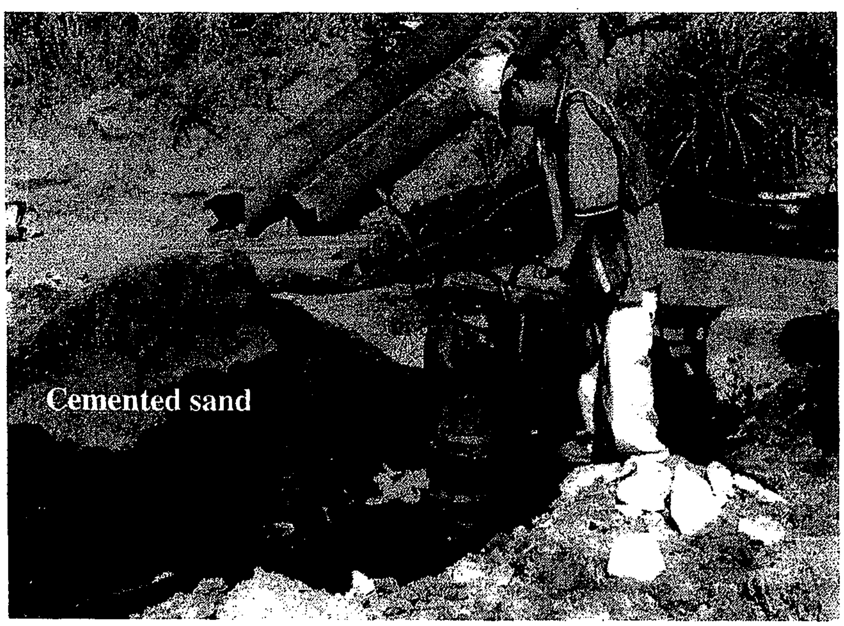


Figure 5.13 Compacting the cemented sand using a vibrator, Sugarland, Texas (Batch CS-4, FS-10, 7% Cemented Sand, Site-B)

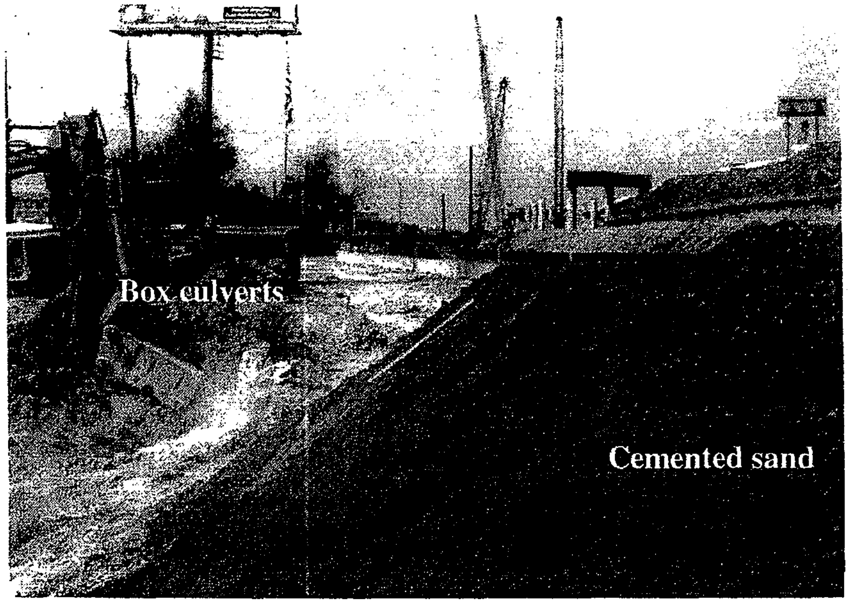


Figure 5.14 Cemented sand and box culverts for storm sewer US 59 & HIGHWAY 90 Intersection, Sugarland, Texas (Batch CS-4, FS-10, 7% cemented sand, Site-B)

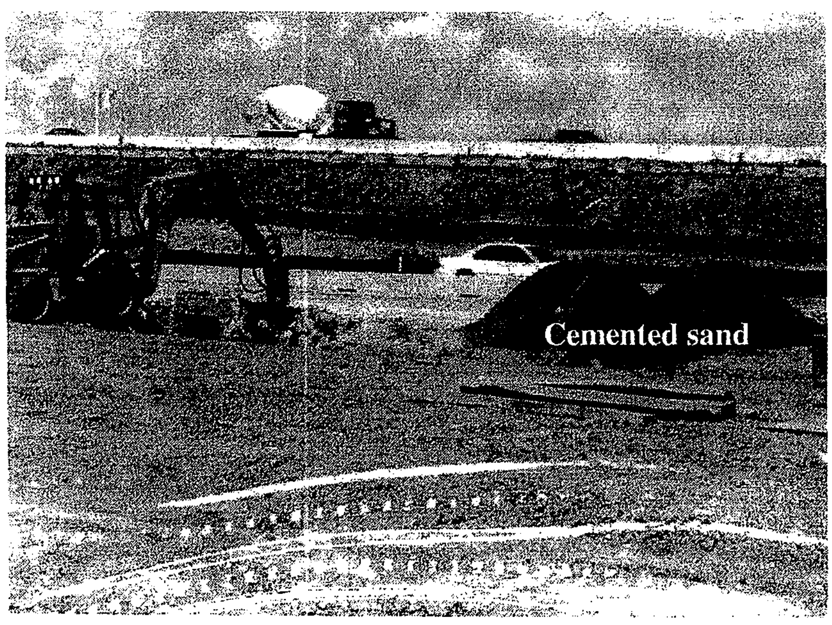


Figure 5.15 Construction site (Batch CS-4, FS-10, 7% cemented sand, Site-B)

Table 5. 4 Engineering properties of Batch CS-4 (FS-10)
(7 % cemented sand, field sample, Site-A)

Batch CS-4 (Site-A)		Curing time			
		7-day	28-day	6-month	1 year
7% cement Cubic sample (2×2×2)	Unit weight (lb/ft^3)	1 : 100 #2 : 98 Aver :99	1 : 98.1 #2 : 103.5 Aver : 100.4	1 : 101 #2 : 100 Aver : 101	1 : 102 #2 : 101 Aver : 102#
	Pulse velocity (ft/sec)	1 : 5123 #2 : 5209 Aver : 5166	1 : 6561 #2 : 6830 Aver : 6732	1 : 6834 #2 : 6925 Aver : 6880	1 : 7120 #2 : 7050 Aver : 7085
	Compressive strength (psi)	#1 : 330 #2 : 360 Aver : 345	#1 : 405 #2 : 391 Aver : 398	#1 : 402 #2 : 408 Aver : 405	1 : 405 #2 : 415 Aver : 410
	Elastic modulus (ksi)	251	300	301	315
7% cement cylindrical-1 (Dia :1.5 Height: 3)	Unit weight (lb/ft^3)	1 : 100.4 #2 : 102.3 Aver :101.4	1 : 101.1 #2 : 105.3 Aver : 103.2	1 : 102 #2 : 103 Aver : 103	1 : 101 #2 : 104 Aver : 103
	Pulse velocity (ft/sec)	1 : 1460 #2 : 1496 Aver : 1478	1 : 5090 #2 : 5449 Aver : 5270	1 : 5400 #2 : 5540 Aver : 5470	1 : 5980 #2 : 5870 Aver : 5925
	Compressive strength (psi)	#1 : 185 #2 : 223 Aver : 204	#1 :277 #2 : 279 Aver : 273	#1 : 276 #2 : 280 Aver : 278	#1 : 276 #2 : 284 Aver : 280
	Elastic modulus (ksi)	150	183	200	210
7% cement cylindrical-2 (Dia :3 Height: 6)	Unit weight (lb/ft^3)	1 : 103 #2 : 105 Aver : 104	1 : 104 #2 : 109 Aver : 107	1 : 106 #2 : 109 Aver : 108	1 : 107 #2 : 107 Aver : 107
	Pulse velocity (ft/sec)	1 : 5023 #2 : 5239 Aver : 5131	1 : 5586 #2 : 6075 Aver : 5780	1 : 5890 #2 : 6125 Aver : 6007	1 : 6492 #2 : 6494 Aver : 6493
	Compressive strength (psi)	#1 :115 #2 : 145 Aver : 130	#1 : 175 #2 : 153 Aver : 164	#1 : 170 #2 : 176 Aver : 173	#1 : 192 #2 : 170 Aver :181
	Elastic modulus (ksi)	95	120	130	135

Table 5. 5 Engineering properties of Batch CS-4b (FS-10)
(7 % cemented sand, field sample, Site-B)

Batch CS-4 (Site-B)		Curing time			
		7-day	28-day	6-month	1 year
7% cement cylindrical-1 (Dia :1.5 Height: 3)	Unit weight (lb/ft^3)	1 : 107 #2 : 109 Aver 108	1 : 106 #2 : 108 Aver : 107	1 : 105 #2 : 107 Aver : 106	#1 : 107 #2 : 109 Aver :108
	Pulse velocity (ft/sec)	1 : 6452 #2 : 7074 Aver : 6763	1 : 7982 #2 : 7500 Aver : 7741	1 : 8073 #2 : 8100 Aver : 8087	#1 : 8105 #2 : 8203 Aver : 8154
	Compressive strength (psi)	#1 : 540 #2 : 618 Aver : 580	#1 :844 #2 : 890 Aver : 867	#1 :863 #2 : 872 Aver : 868	#1 : 885 #2 : 895 Aver :890
	Elastic modulus (ksi)	400	600	610	650
7% cement cylindrical-2 (Dia :3 Height: 6)	Unit weight (lb/ft^3)	1 : 106 #2 : 107 Aver : 107	1 :105 #2 : 107 Aver : 106	1 : 106 #2 : 108 Aver : 107	#1 : 106 #2 : 107 Aver :107
	Pulse velocity (ft/sec)	1 : 6410 #2 : 6756 Aver : 6583	1 : 7350 #2 : 7430 Aver : 7390	1 : 8050 #2 : 8130 Aver : 8090	#1 : 8333 #2 : 8333 Aver :8333
	Compressive strength (psi)	#1 : 325 #2 : 330 Aver : 327	#1 : 490 #2 : 520 Aver : 505	#1 : 510 #2 : 530 Aver : 520	#1 : 540 #2 : 533 Aver :537
	Elastic modulus (ksi)	230	370	400	403

As shown in Fig. 5.17, unit weight varied slightly, with increasing curing time. The average unit weights of cylindrical specimen-1 (Dia: 1.5inch) after 7, 28, 180 day, and 1 year of curing were 108, 107, 106, and 108 lb/ft^3. There is no significant difference in the unit weight with curing time. The average unit weight of cylindrical specimen-2 (Dia: 3.0inch) after 7, 28, and 180 days, and 1 year of curing were 107, 106, 107, and 107 lb/ft^3. There was also no significant difference in the unit weight with curing time.

5.5.2 Pulse velocity

Pulse velocities of the two field samples (Site-A, and Site-B) were measured and the variation of pulse velocity with curing time is summarized in Tables 5.4 and 5.5. As curing time increased, pulse velocity also increased. The average pulse velocity of Site-A samples was higher compared to Site-B.

5.5.2.1 Pulse velocity (Site-A: US 59 S, Sugarland, Texas)

Variation of pulse velocity with curing time is shown in Fig. 5.18. The pulse velocity increased with increasing curing time. The average pulse velocity of cubic specimen after 7, 28, and 180 days, and 1 year of curing, was 5166, 6732, 6880, and 7085 ft/sec respectively. The average pulse velocity of cylindrical-1 specimen (Dia: 1.5inch) after 7 day, 28 day, and 180 day, and 1 year of curing was 1478, 5270, 5470, and 5925 ft/sec. The average pulse velocity of cylindrical-2 specimen (Dia: 3.0inch) after 7, 28, and 180 day, and 1 year of curing was 5131, 5780, 6007, and 6493 ft/sec. Cubic specimen pulse velocity increased by 30% from 7 to 28 days of curing time. Cylindrical-1, and cylindrical-2 pulse velocity were increased 350% and 13% from 7 to 28 days of curing time.

5.5.2.2 Pulse velocity (Site-B: Intersection of US 59 & HWY 90, Sugarland, Texas)

Variation of pulse velocity with curing time is shown in Fig. 5.19. The pulse velocity increased with increasing the curing time. The average pulse velocity of cylindrical specimen 1(Dia: 1.5 inch) after 7 day, 28 day, 180 day, and 1year of curing were 6763, 7741, 8087, and 8154 ft/sec respectively.

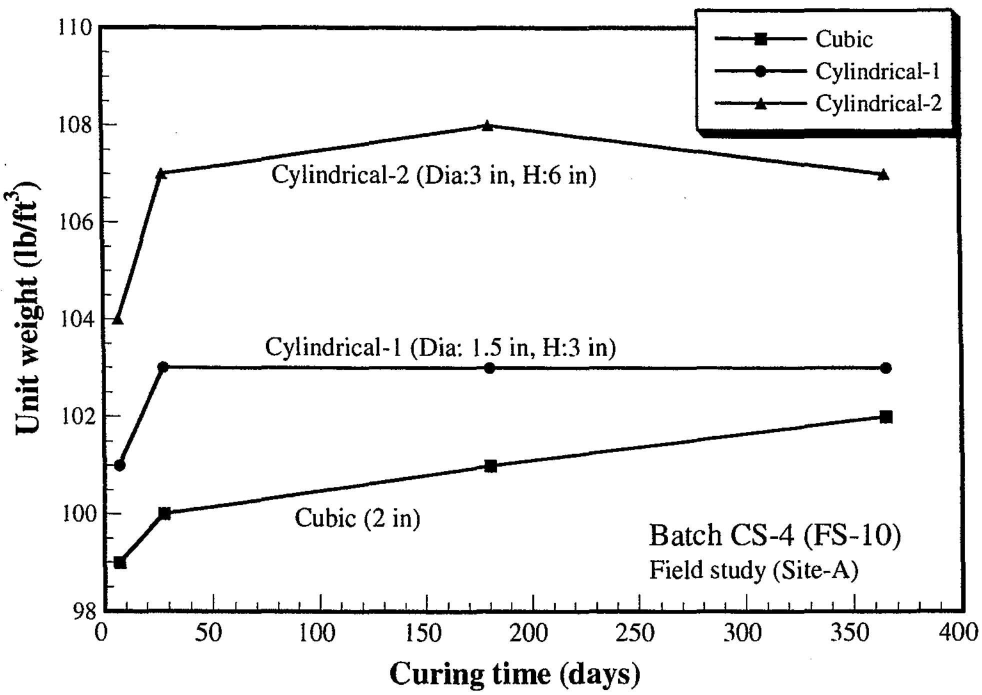


Figure 5.16 Variation of unit weight with curing time (Batch CS-4, field study, Houston, Texas)

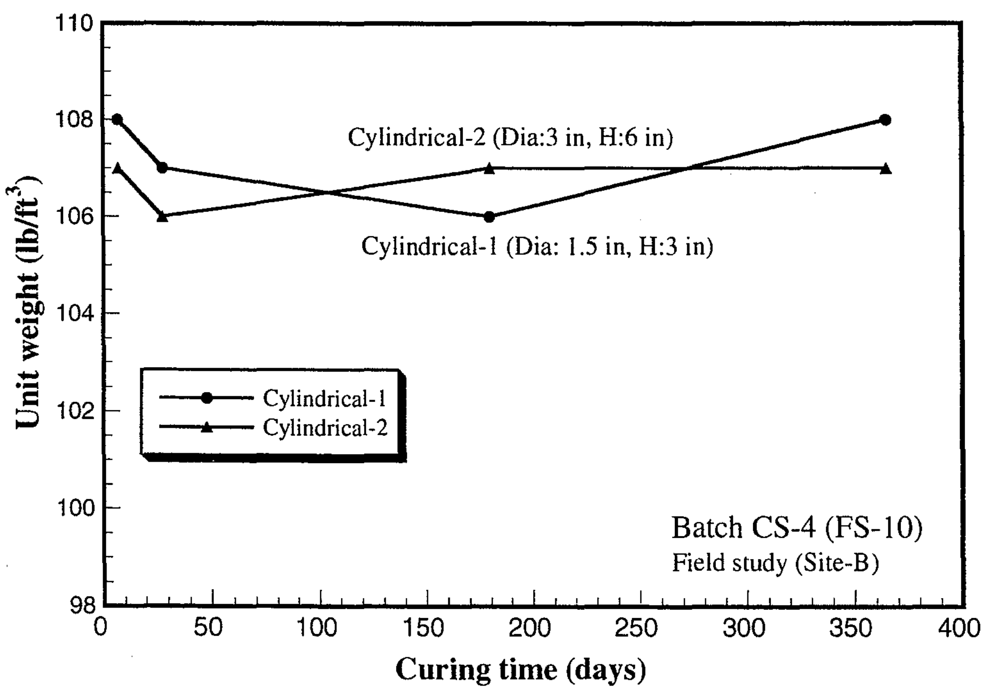


Figure 5.17 Variation of unit weight with curing time (Batch CS-4, field study, Houston, Texas)

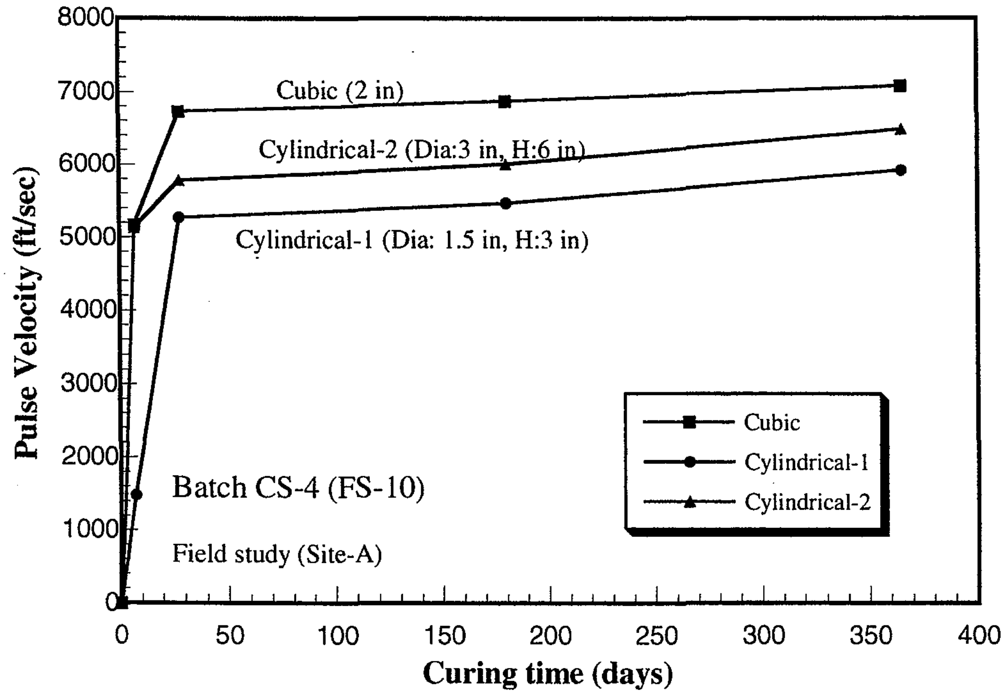


Figure 5.18 Variation of pulse velocity with curing time (Batch CS-4. field study, Site-A)

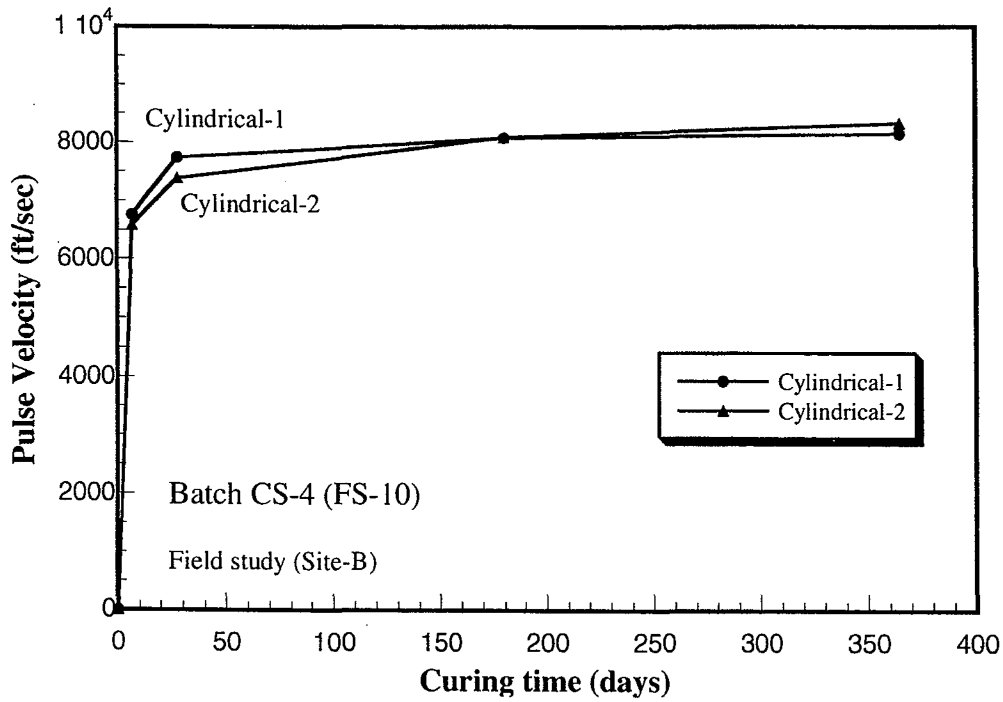


Figure 5.19 Variation of pulse velocity with curing time (Batch CS-4. field study, Site-B)

The average pulse velocity of cylindrical specimen 2(Dia: 3.0 inch) after 7 day, 28 day, 180 day, and 1year of curing were 6583, 7390, 8090, and 8333 ft/sec respectively. Cylindrical-1, and cylindrical-2 pulse velocity increased by 14 and 12% respectively from 7 to 28 days of curing time.

5.5.3 Unconfined compressive strength

Unconfined compressive strength tests were performed for samples from the two field sites up to 1 year. Unconfined compressive strength varied from 115 to 895 psi

5.5.3.1 Unconfined compressive strength (Site-A: US 59 S, Sugarland, Texas)

Variation of unconfined compressive strength of Site-A with curing time is shown in Fig. 5.20. The average 7 day compressive strength of cubic, cylindrical-1, and cylindrical-2 were 345, 204, and 130 psi respectively. The average 28 day compressive strength of cubic, cylindrical-1, and cylindrical-2 were 398, 273, and 164 psi respectively. From the 7 day to 28 day curing time, the average unconfined compressive strength of cubic, cylindrical-1, and cylindrical-2 increased by 15%, 34% and 26% respectively. Unconfined compressive strength increased slightly after 28 day of curing.

5.5.3.2 Unconfined compressive strength (Site-B, Sugarland, Texas)

Variation of unconfined compressive strength of samples from sugarland, Texas (Site-B) with curing time is shown in Fig. 5.21. The average 7 day compressive strength of cylindrical-1, and cylindrical-2 were 580, and 327 psi respectively. The average 28 day compressive strength of cylindrical-1, and cylindrical-2 were 867, and 505 psi. From the 7 day to 28 day curing time, the average unconfined compressive strength of cylindrical-1, and cylindrical-2 increased by 50% and 54% respectively. As shown in Fig. 5.21, unconfined compressive strength increased slightly after 28 day of curing.

5.6 ANALYSIS OF CEMENTD SAND (Laboratory study VS. Field study)

Total of 50 laboratory samples and 40 field samples have been tested. So far, total of 224 different types of tests were performed to characterize the cemented sand as summarized in Table 5.6.

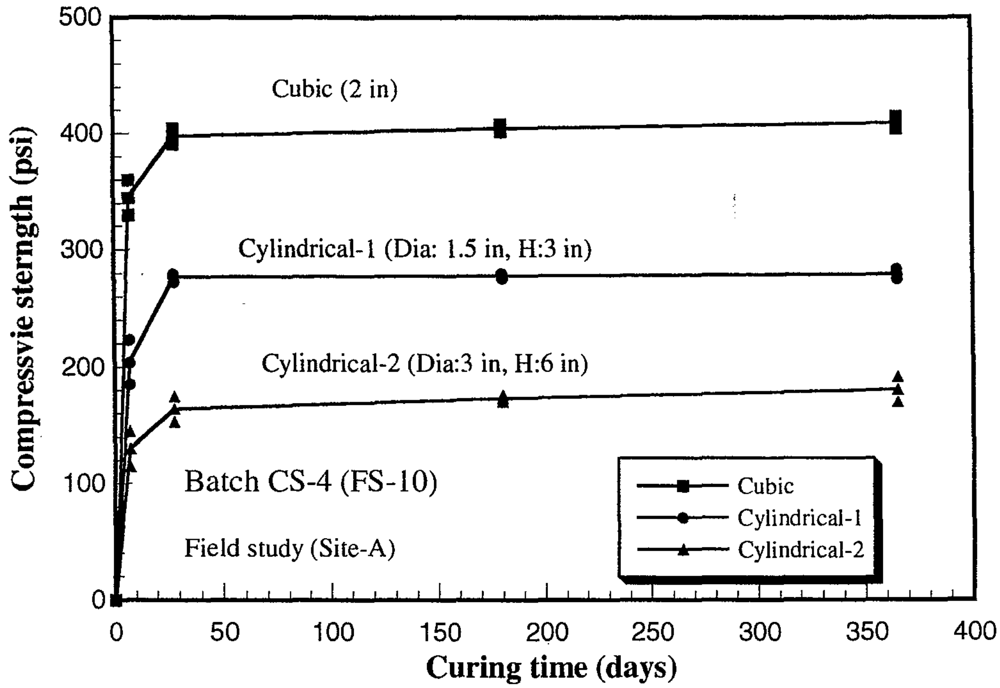


Figure 5.20 Unconfined compressive strength with varying specimen size, shape, and curing time (Batch CS-4. field study, Site-A)

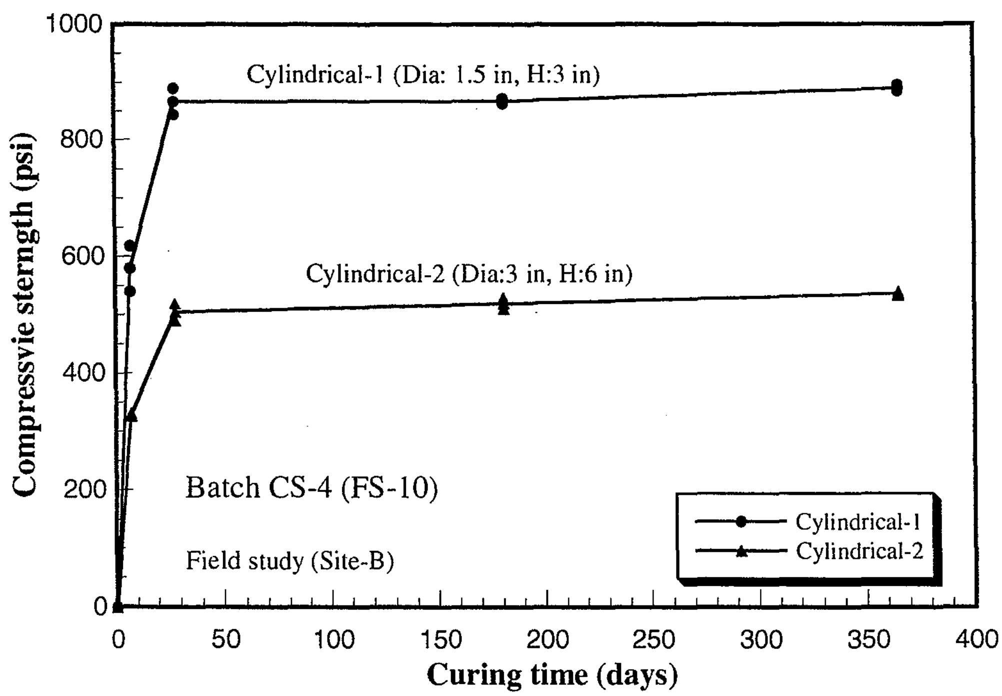


Figure 5.21 Unconfined compressive strength with varying specimen size, shape, and curing time (Batch CS-4. field study, Site-B)

Table 5.6 Summary of tests for laboratory and field samples

Test	Laboratory test			Field test
	CS-1	CS-2	CS-3	CS-4
Unit weight	None	None	18	40
Pulse velocity	None	None	18	40
Specific resistivity	18	None	None	None
Compressive strength	18	14	18	40
Sum	36	14	54	120
Total	Laboratory test: 104			Field test : 120
Remarks	Total test : 224			

Total of 90 compressive strength tests (50 laboratory samples and 40 field samples) were performed to evaluate the strength properties with curing time. Total of 58 unit weight and another 58 pulse velocity tests were performed to evaluate engineering properties of cemented sand. Total of 18 specific resistivity tests were performed on laboratory samples to evaluate the environmental properties of cemented sand. Based on these test results, performance of laboratory samples are compared to field samples.

5.6.1 Unit weight

The unit weights of the laboratory and field samples are compared as in Fig. 5.22. The average unit weight of laboratory sample was 116 lb/ft^3 with a standard deviation of 6.8 and C.O.V of 0.06. The average unit weight of field sample was 105 lb/ft^3 with a standard deviation of 2.9 and C.O.V of 0.03. As shown in Fig. 5.23, the unit weight of laboratory sample was 12% higher than that of field samples.

5.6.2 Pulse velocity

The pulse velocities of laboratory and field samples are compared as in Fig. 5.24. The average pulse velocity of laboratory sample was 6145 ft/sec with a standard deviation of 708 and C.O.V of 0.11. The average pulse velocity of field samples was 6430 ft/sec with a standard deviation of 1565 and C.O.V of 0.24. Pulse velocity of field samples was 2% higher than that of laboratory samples (Fig. 5.25).

5.6.3 Unconfined compressive strength

The unconfined compressive strengths of laboratory and field sample are compared as in Fig. 5.26. through 5.29. The average unconfined compressive strength of laboratory sample was 232 psi with a standard deviation of 75 and C.O.V of 0.32. The average unconfined compressive strength of field sample was 417 psi with a standard deviation of 237 and C.O.V of 0.57. As shown in Fig. 5.26, compressive strengths of all the samples (Site-A) and 38% of sample (Site-B) were higher than that of laboratory samples. The average compressive strength of laboratory and field cubic specimen after 28 days of curing was 327, and 398 psi respectively. The field cubic specimen had higher compressive strength by 22% than laboratory cubic specimen.

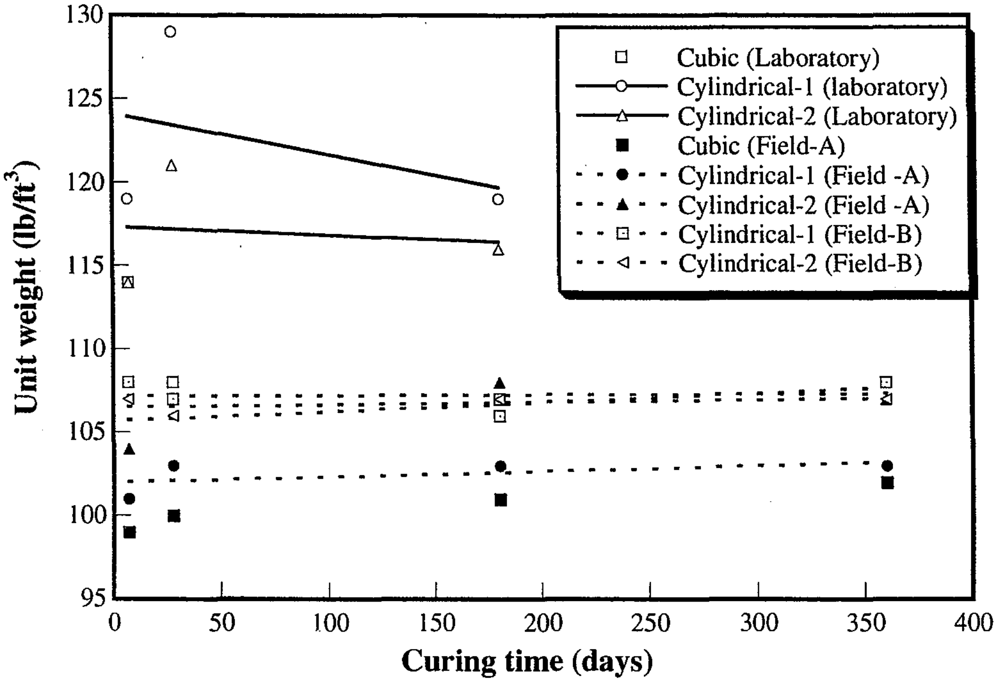


Figure 5.22 Comparison of the unit weight with laboratory and field samples

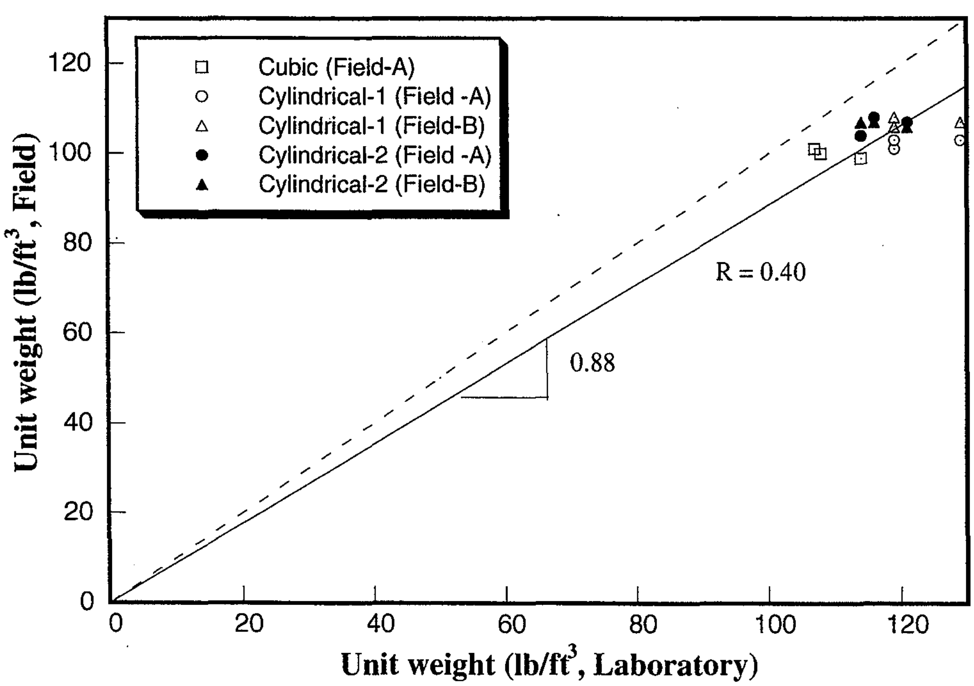


Figure 5.23 Comparison of the unit weight with laboratory and field samples

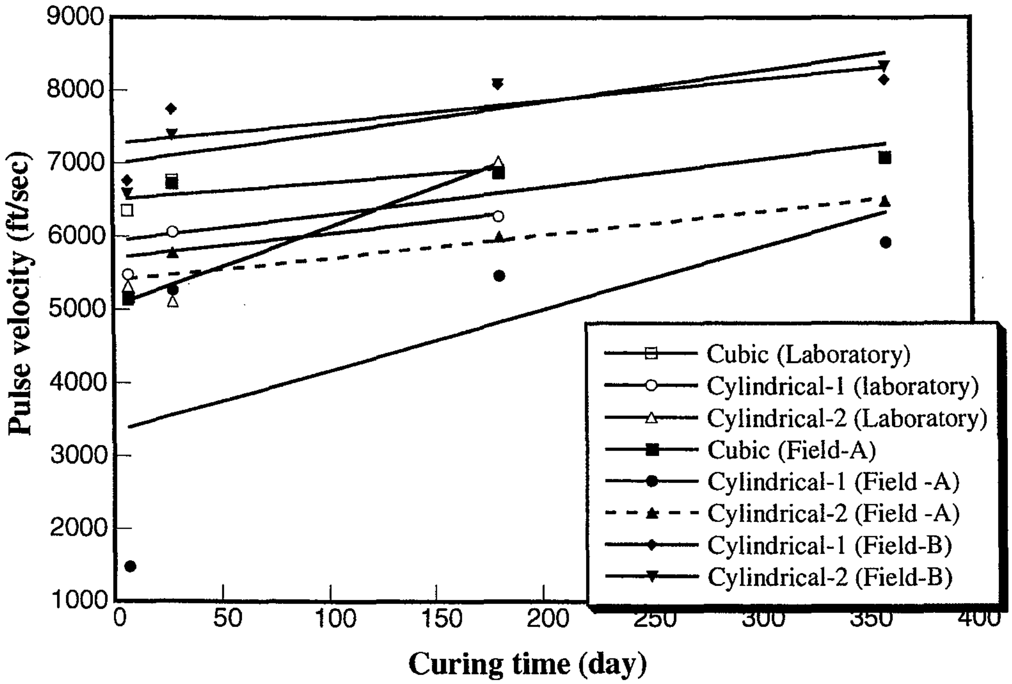


Figure 5.24 Comparison of the pulse velocity with laboratory and field samples

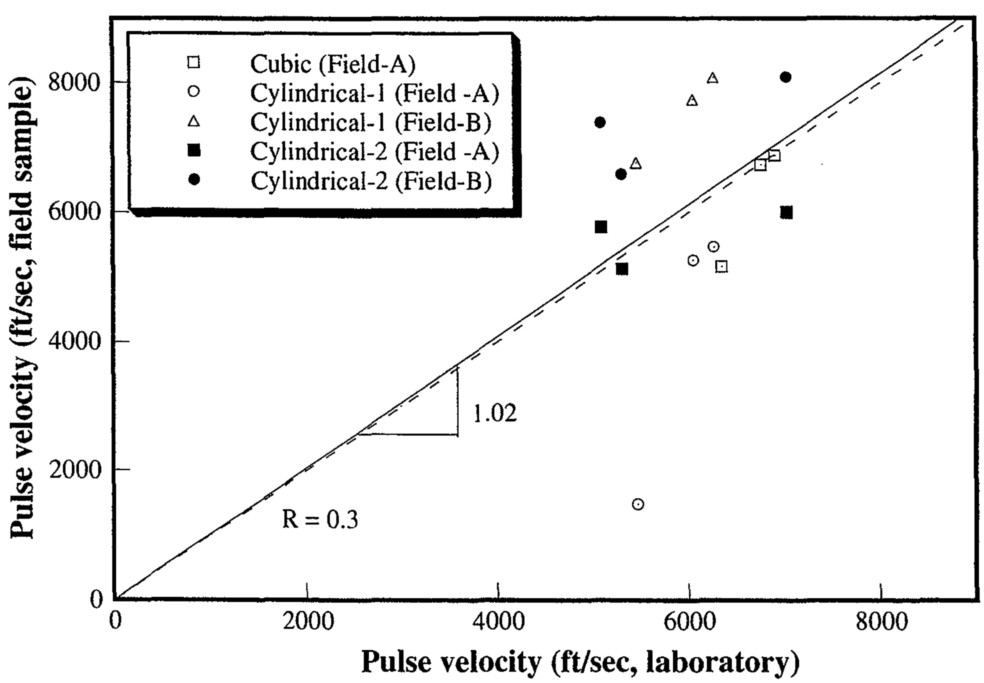


Figure 5.25 Comparison of the pulse velocity with laboratory and field samples

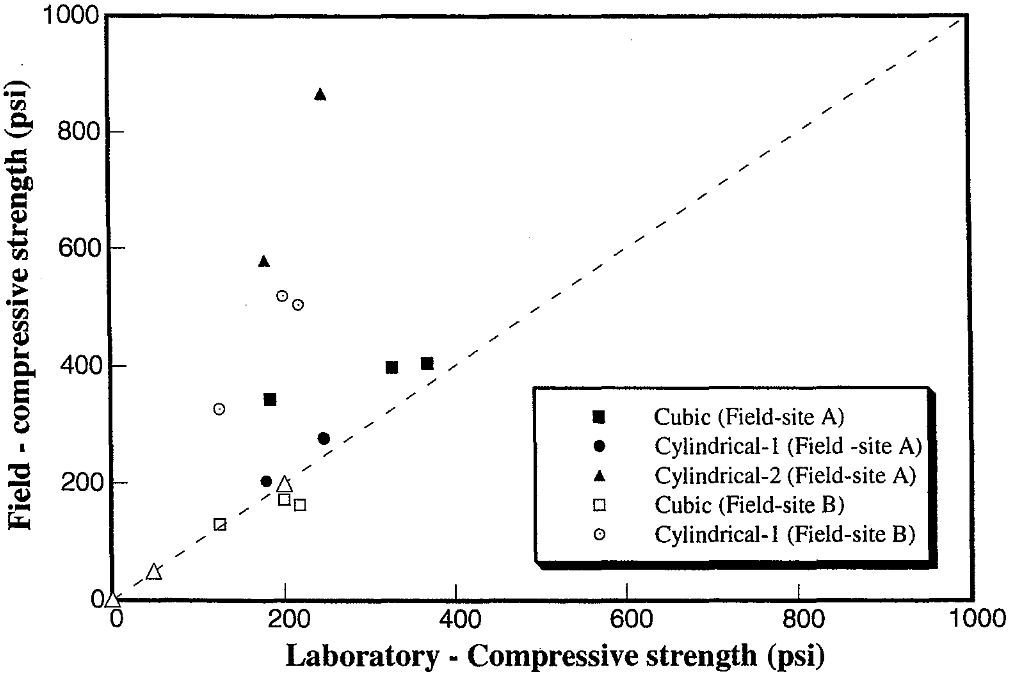


Figure 5.26 Comparison of the unconfined compressive strength with laboratory and field data

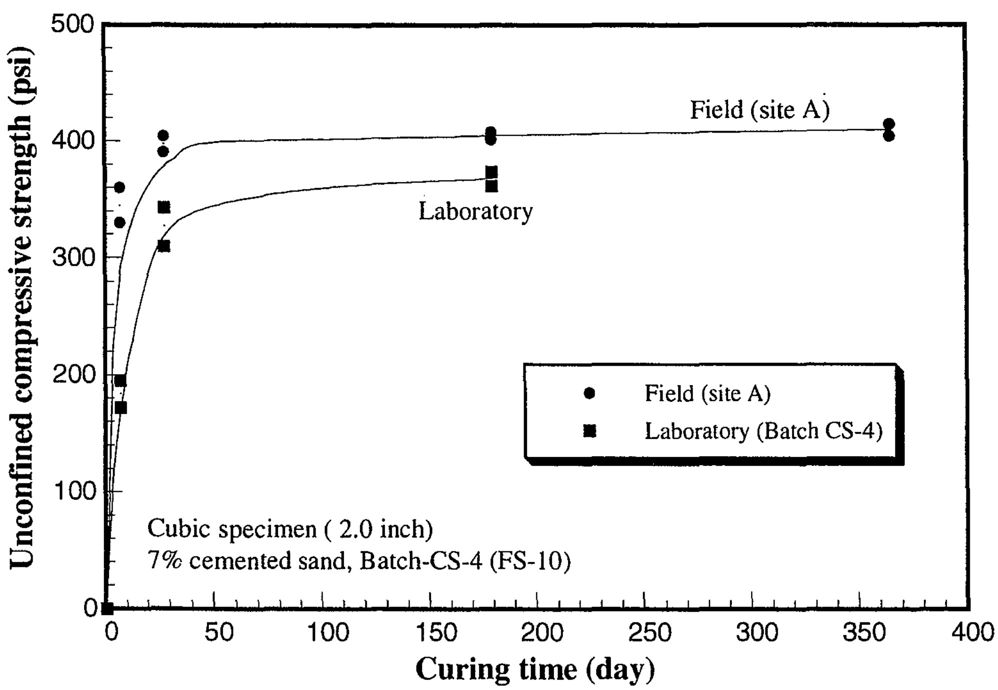


Figure 5.27 Comparison of the unconfined compressive strength with laboratory and field data (cubic specimen)

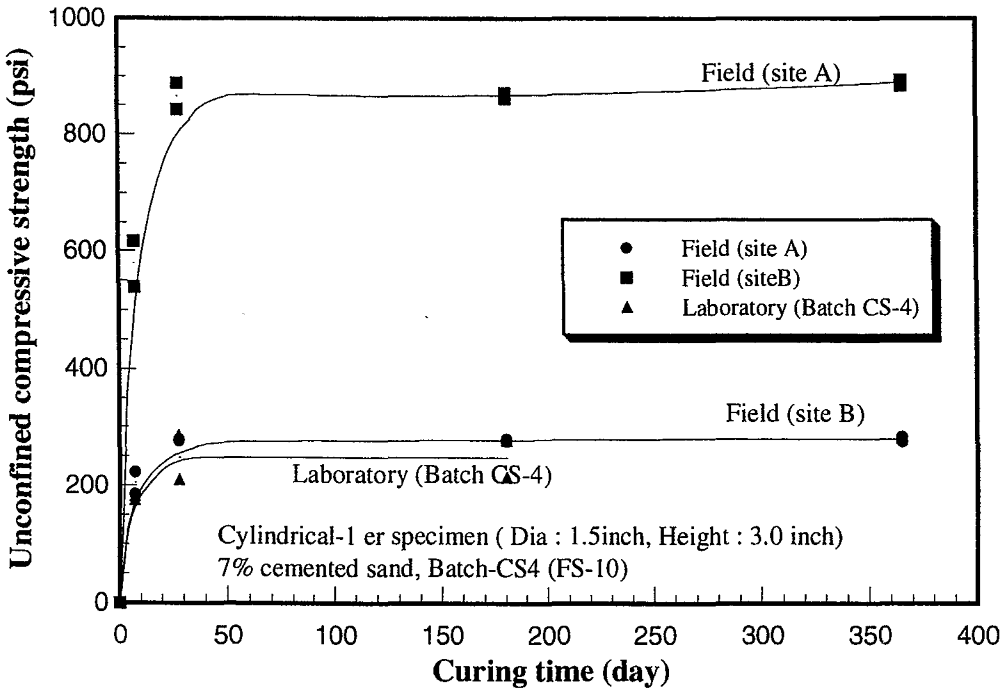


Figure 5.28 Comparison of the compressive strength with laboratory and field data (cylindrical-1 specimen)

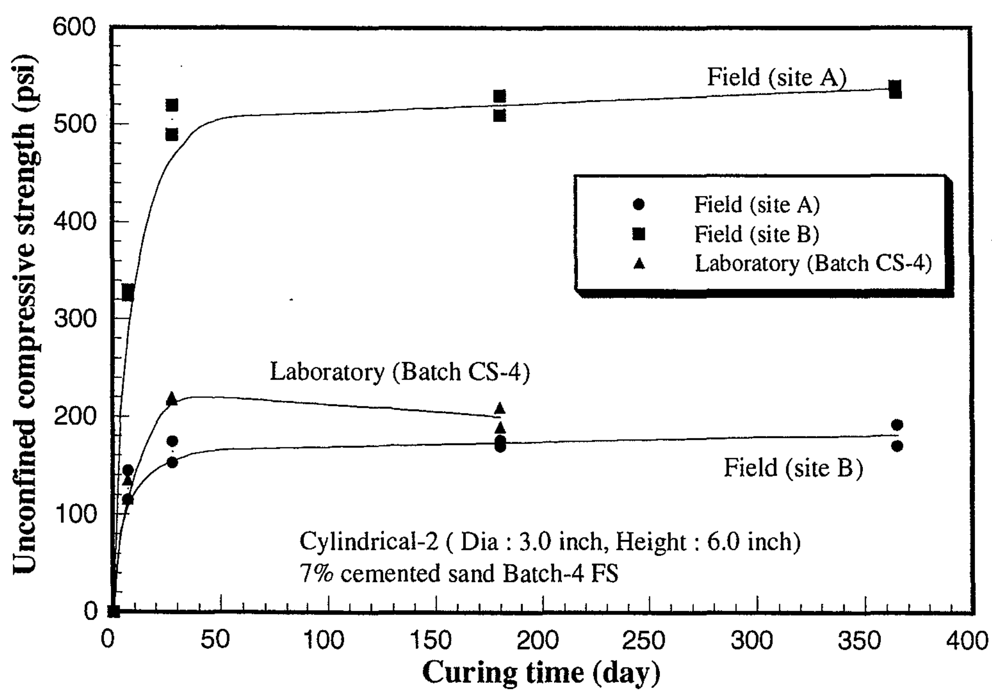


Figure 5.29 Comparison of the unconfined compressive strength with laboratory and field data (cylindrical-2 specimen)

The average compressive strength of laboratory and field-cylindrical-1(Site-A, and B, Dia:1.5 in) specimen after 28 day of curing were 248, 277, and 867 psi respectively. The field-cylindrical-1 (Site-B) specimen had higher compressive strength by 250% than laboratory cubic specimen. The average compressive strength of laboratory and field-cylindrical-2 (Site-A, B, Dia:3.0 in) specimen after 28 day of curing was 219, 164, and 505 psi respectively. The field-cylindrical-2 (Site-B) specimen had higher compressive strength by 130% than laboratory cubic specimen. The average compressive strength of laboratory and field-cubic specimen after 28 day of curing was 327, and 398 psi respectively. After 28 days of curing, there was slight difference in compressive strength. Average ratio of 7 day compressive strength to the 28 days compressive strength for laboratory sample was 0.62 with a standard deviation of 0.09 and C.O.V of 0.15 and for the field samples, Average ratio of 7 day compressive strength to the 28 days compressive was 0.74 with a standard deviation of 0.09 and C.O.V of 0.12.

5.6.4 Compressive strength – Cement content

Current study results of average compressive strength are compared to the data from literature in Fig. 5.30. For curing time of 7 days (cylindrical specimen (diameter: 1.5 inch, height: 3 inch), compressive strength had a liner relationship with cement content X_c as follows

$$\sigma_c = 33.5 \bullet (X_c\%) \qquad (5.1)$$

Where, σ_c : Unconfined compressive strength (psi)

5.6.5 Compressive strength – Pulse velocity

Relationship of compressive strength to pulse velocity was investigated. Compressive strength, σ_c was related to the pulse velocity, V_p as shown in Fig. 5. 31. The relationship was as follow:

$$\sigma_c = 0.105\,(V_p) - 307 \qquad (5.2)$$

Where, V_p: pulse velocity (ft/sec)

σ_c: Unconfined compressive strength (psi)

5.6.6 Compressive strength – Young's Modulus

Compressive strengths are compared with Young's Modulus in Fig. 5. 32. Compressive strength is linearly related to the modulus and can be represented as follows:

$$E_{ci} = m\sigma_c \tag{5.3}$$

Where, E_{ci} : Modulus (psi)

σ_c : Unconfined compressive strength (psi)

Where m is the non-dimensional parameter (slope of the line). The parameter m was 720 (R=0.99).

5.6.7 Shape and size effect of compressive strength

Batch CS-4 cemented sand was used to study the size and shape effects of engineering properties. As shown in Fig. 5.33, the average ratio of cylindrical-1/cubic, and cylindrical-2/cubic compressive strength were 0.7 and 0.5 respectively. For the laboratory cylindrical-1 (D:1.5 in, H:3.0 in) samples, the ratio of cylindrical/cubic was 0.66. However, for the field cylindrical-1 (D:1.5 in, H:3.0 in) samples, the ratio of cylindrical/cubic was 0.8. Compressive strengths were higher in cubic sample than cylindrical sample. As increased the size of sample, compressive strength decreased. The compressive strength was almost same for the cylindrical-1 (D:1.5 in, H:3.0 in) samples. However, for the cylindrical-2 (D:3.0 in, H:6.0 in) sample, compressive strengths were higher in laboratory sample than that of field samples.

5.7 MODIFIED SPECIFICATION FOR CEMENTED SAND

5.7.1 Modified specification (ITEM 400.6): Cement stabilized backfill for structures

When shown on the plans, the excavation shall be backfilled to the elevation shown with cement stabilized backfill. Unless otherwise shown on the plans, cement stabilized backfill shall contain aggregates, water and a minimum of seven (7) percent Portland cement based on the dry mass of aggregate, in accordance with Test Method Tex-120-E.

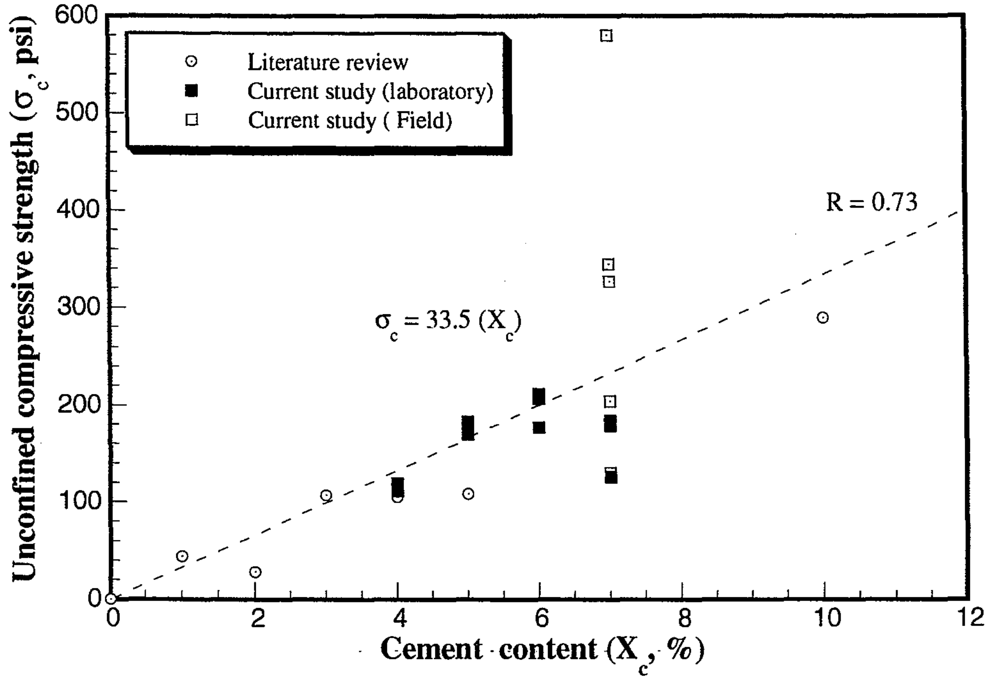


Figure 5.30 Comparison of unconfined compressive strength with cement content

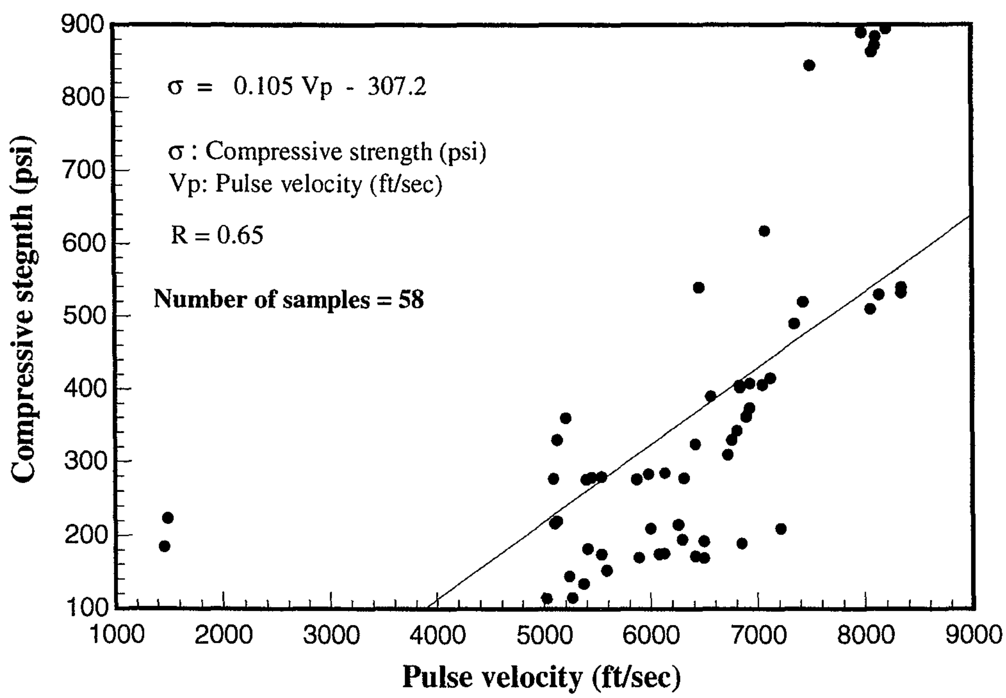


Figure 5.31 Comparison of unconfined compressive strength with pulse velocity

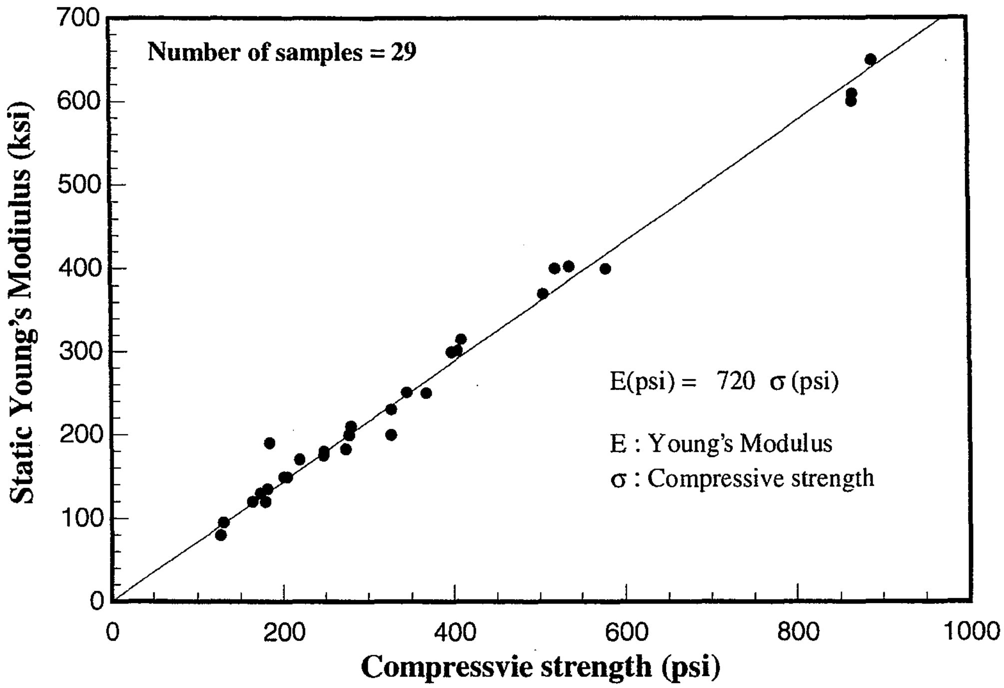


Figure 5.32 Comparison of unconfined compressive strength with modulus

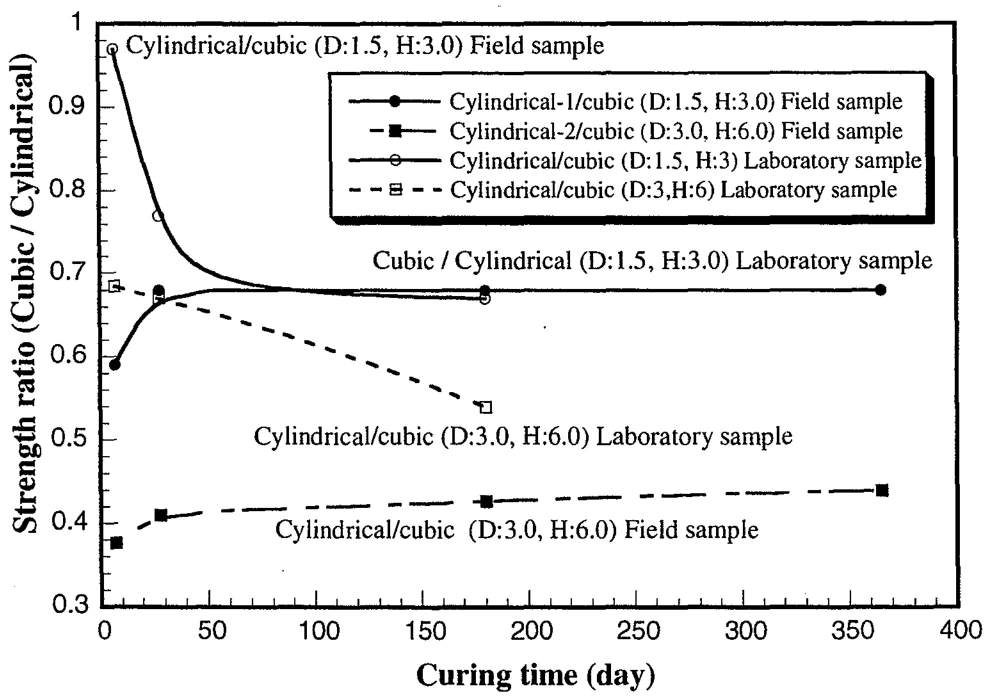


Figure 5.33 Unconfined compressive strength ratio of cubic and cylindrical specimen

Aggregate shall be **natural sand or foundry sand (ferrous)** or as shown on the plans as approved by the Engineer. **Foundry sand should satisfy the DMS-11000 guidelines for Nonhazardous Recyclable Material (NRM).**

5.7.2 Modified specification (ITEM 423.2): Backfill material for retaining wall

(3) Unless otherwise shown on the plans, the Contractor shall have the option of stabilizing backfill for MSE walls with five (5) percent Portland cement by dry mass of the backfill material.

When Type A backfill is shown on the plans, the contractor may use Type B backfill **or foundry sand (ferrous)** with five (5) percent Portland Cement by dry mass of the backfill material. **Foundry sand should satisfy the DMS-11000 guidelines for Nonhazardous Recyclable Material (NRM).**

The resistivity of unstabilized foundry sand shall not be less than 3000 ohms-cm as determined by test Method -129-E. The pH range shall be from 5.5 to 10.0 as determined by Test Method Tex-128-E.

5.8 CONCLUSION

Behavior of cemented sands was investigated using laboratory and field samples. Several property relationships have been developed to guide the designing of cemented sand using foundry sand. Based on the experimental results and analysis of the test data following conclusions are advanced:

1. **Cemented sand:** By adding 4 to 7% cement to the foundry sands, it is possible to achieve a compressive strength of over 100 psi in 7 days. The compressive strength increased with increasing cement content and curing time.
2. **Unit weight:** Unit weight of cemented sand varied from 99 to 108 pcf. Unit weight of cemented sand decreased with curing time. The laboratory samples had higher unit weight compared to the field samples.
3. **Specific resistivity:** Electrical resistivity of cemented sand was over 3000 ohms-cm and was influenced by the cement content and curing time.

4. **Property Relationship:** Compressive strength was related to the compressive modulus, pulse velocity and cement content for the cemented sand.
5. **Specimen Size and shape Effect**: The compressive strength is high when using the small specimen and was related to the specimen size. The compressive strength of cubic specimens was higher than the cylindrical specimens.
6. **Tx DOT Specification,** (ITEM 400.6-Cemented stabilized backfill for structures, ITEM 423.2-Backfill material for retaining wall), has been modified to include FS in the cement stabilized sand.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Foundry sand (FS) is a by-product of the metal casting industry and only about 20 percent of the FS generated annually currently are recovered and used and the rest are disposed in landfills. Research has shown that FS has the potential for use in highway construction and several other civil engineering applications. In this study, an extensive literature review was undertaken to collect information on the potential FS applications, case studies on FS use, engineering and environmental properties of FS, relevant regulations and specifications. The information was synthesized to determine the two potential applications for FS in Texas. A survey was undertaken to determine the availability of FS in Texas. The study also included testing of number of FS available in the State of Texas to determine their engineering and environmental properties and compare it to published data from other locations outside Texas. A detailed evaluation of flowable fill and cemented sand using the FS in Texas was performed by combining laboratory tests and field applications. Field tests on the flowable fill and cemented sand were done in the Brownwood District and Houston District respectively.

EPA's Final Rule in 40 CFR Part 247 (2000) is a comprehensive guideline for procurement of products containing recovered materials. It is anticipated that the proposed action will foster markets for materials recovered from solid waste by using government purchasing power to simulate the use of these materials in the manufacture of new products (Federal Register/Vol. 65, No. 12, January 19, 2000). The Final Rule includes the use of ferrous foundry sands in flowable fill. It must be noted that the EPA has removed any characterization of non-ferrous foundry sands as hazardous in the final Comprehensive Procurement Guideline (CPG).

The primary objective of this project is to verify the availability and suitability of Texas-generated FS for TxDOT and to develop specifications for use of these sands in TxDOT construction and maintenance applications. Based on the TxDOT needs, use of foundry sand in flowable fill and cemented sand was investigated. Based on this study following conclusions and recommendations are advanced:

(1) Based on the literature review, some of the most popular applications for foundry sand are in roadway sub-base, embankment, asphalt concrete and flowable fill. Also number

of other applications have been identified where foundry sand has been used. Foundry sand has not been used in cemented sand.

(2) Few state DOTs have specifications for using foundry sand in flowable fill mixes. EPA's final rule on comprehensive guidelines for procurement of products containing recovered materials recommends the use of ferrous foundry sand in flowable fills.

(3) Based on the survey, over 93,000 tons of FS is produced in Texas of which over 60,000 tons are available for TxDOT projects in 13 Districts. There is over 3.3 million tons of FS in stock piles in Texas.

(4) Total of ten foundry sands were randomly collected from around the State of Texas for the laboratory study. The specific gravity of the Texas foundry sands varied from 2.4 to 2.68. The moisture content of the foundry sands varied from 0 to 5.5%. These values are within the range of values reported in the literature.

(5) Most of the of Texas foundry sands tested were classified according to USCS as SP. Particle size of all the Texas FS tested were finer than ASTM C33 sand. The pH of the FS varied from 7 to 10.2. These values are within the range of values reported in the literature.

(6) The pH of the Texas foundry sands varied from 7 to 10.2. Except for one FS, all the others Texas FS had LOI in the range of 0 to 7%. These values are within the range of values reported in the literature.

(7) Few FS were selected for the TCLP and TNRCC tests. Analyses of 27 metals showed that all the tested FS sands passed the tests.

(8) Leaching tests (total analysis) on a selected foundry sand showed that based on SVOC analyses only flouranthene and pyrene were present and the concentrations were below TNRCC RRS2 limits. VOC analysis indicated that all the chemicals analyzed were below the detection limits. Total metal analyses indicated that Al, P and Pb were above the GW-Res limit but only P exceeded the TNRCC GWP-Res limit. No mercury or TPH were detected in the FS. The FS-9a tested can be characterized as non-hazardous material.

(9) Specific resistance of selected FS sand at the natural moisture content was higher than 3000 ohm-cm which is specified by TxDOT as the minimum for backfill materials.

(10) Specification for foundry sand has been developed. MSDS sheet and material specification for Texas foundry sand has been developed.

(11) Design approach for flowable fill mixes has been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio. Laboratory samples showed higher strength and pulse velocity compared to the field samples. Field sample strength was 330 psi after one year. Property relationships for flowable fills with Texas foundry sands have been developed. TxDOT special Specification (ITEM 4438-Flowable Backfill), has been modified to include foundry sand.

(12) Design approach for cemented sand mixes has been developed by varying the foundry sand-to-cement ratio and water-to-cement ratio. It was possible to achieve a compressive strength of over 100 psi in 7 days. Property relationships for cemented sand with Texas foundry sands have been developed. TxDOT Specifications on cement stabilized sand (ITEM 400.6-Cement stabilized backfill for structures; ITEM 423.2-Backfill material for retaining wall), have been modified to include foundry sand.

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APPENDIX: A

Miscellaneous

(1) **TCMA Survey Sheet**

(2) **MSDS Sheet**

(3) **Engineering Properties of FS**

(4) **Environmental Properties of FS**

(5) **Federal Registar 40 CFR 247 (2000)**

TEXAS CAST METALS ASSOCIATION (TCMA)

The TCMA is working with the Texas Department of Transportation (TXDOT) to investigate the potential of using Foundry Sand in their applications. TXDOT has awarded the University of Houston a grant to research these potential uses and to develop a set of pilot projects.

The TCMA is sending this survey to all the foundries in Texas, so that we can gather and issue to TXDOT and the University of Houston the information that they need to complete their research.

Please answer each question and return in the enclosed envelope by May 1, 1999

(1) What type of metal does your foundry produce? (Circle all that apply)

Steel Iron Stainless Steel Aluminum Brass/Bronze

(2) What type of molding sand process(s) do you use?

Green Sand Chemically Bonded Sand

(3) How many tons-per-year of foundry sand are produced in the molding process(s) identified above?

____

(4) Do you currently have foundry sand that is clean of core butts, slag, metal, debris, etc., that would be available for use in a TXDOT project? ____________________

(5) If the answer to (question #4) is "yes", please estimate the stockpiled volume in cubic yards.

____

(6) What percentage of the foundry sand identified in (question #3) could be available for future TXDOT projects, if there was an economic benefit? (Circle one.)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

(7) Where is the foundry sand produced?

Name of Foundry: ____

Street Address: ____

City/Zip: ____

Person to Contact: ____

Phone & Fax Number: ____

E-Mail Address: ____

MSDS - Material Safety Data Sheet

Foundry Sand (FS) Used for Transportation Applications

Section 1. Sand Product and Company Identification

Product Names/Trade Names

Foundry sand sold under what name (Green sand, Black sand)

Common Names

Manufacturer's Name **Emergency Telephone Number**

Date Prepared:

Section 2. Composition/Information on Ingredients

Ingredients	Chemical formula	Typical % (By weight)	CAS #
Silica Sand	SiO_2		14808-60-7
Bentonite			
Polymers			
Additives			

Exposure Limits for Ingredients

	OSHA Limit	Time of Exposure
Silica Sand		
Bentonite		
Polymers		
Additives		

Section 3. - Hazard Identification

Emergency Overview:

Ferrous foundry sand material is black in color. It is not flammable, combustible or explosive. It does not cause burns or severe skin or eye irritation.

Inhalation: See Section 11

Eye Contact: Silica sand may cause abrasion of the cornea.

Skin Contact: (Not applicable/Others...)

Ingestion: (Not applicable/Others ....)

Chronic Effects : For adverse health effects see Section 11

Sign and Symptoms of Exposure : Generally, there are no signs or symptoms of exposure to foundry sand.

Medical Conditions Generally Aggravated by Exposure: Similar to common sand. Precautions must be taken with individuals with lung disease.

Section 4.- First Aid Measures

Inhalation: Seek medical attention as needed. Similar to common silica sand.

Eye Contact: Wash immediately with water. If irritation persists, seek medical attention.

Skin Contact: (Not applicable/Others...)

Ingestion: (Not applicable/Others...)

Section 5.- Fire fighting Measures

Is foundry sand flammable? Yes or No

Section 6.- Accidental Release Measures

Is spilling foundry sand a problem? Yes or No

If yes, what must be done? (use dustless methods to clean, dry sweep, wear protective equipment)

Section 7.- Handling and Storage

Precaution during Handling and Use: (Do not breath dust; Use adequate ventilation; Keep airborne dust to a minimum)

Precaution during Storage: (No special requirement; Yes, special precaution must be taken)

What are the precautions for storage? (keep the foundry sand dry; Others)

Section 8.- Exposure Control/Personal Protection

Local Exhaust: (Use adequate ventilation; Keep airborne dust to a minimum)

Respiratory Protection: (No special requirement; Yes, special precaution must be taken)

What is the protection? (provide respiratory protection for crystalline silica; see 29 CFR Section 1910.134 and 42 CFR Section 84; see also ANSI standard Z88.2 on American National Standard for respiratory Protection)

Section 9.- Physical and Environmental Properties

Appearance: Black color sand, granular, crushed or ground **Odor** : (None, Others..........)

Natural Moisture Content (%):

Particle size (in/mm):

Specific gravity:

USCS Classification :

Percentage of Clay(%):

Plastic and Liquid Limit (%):

Leaching of Metals :

Leaching of Organics :

Section 10.- Stability and Reactivity

Stability: Similar to common silica sand. Quartz is stable.

Incompatibility (Materials to Avoid): Similar to common silica sand. Silica will dissolve in hydrofluoric acid and produce a corrosive gas - silicon tetrafluoride.

Hazardous Decomposition or Byproducts: Similar to common silica sand. Silica will dissolve in hydrofluoric acid and produce a corrosive gas - silicon tetrafluoride.

Hazardous Polymerization: Similar to common silica sand. Will not occur.

Section 11.- Toxicological Information

Similar to common silica sand. Concerns will include silicosis, caused by inhalation and retention of respirable silica dust. It must be noted that crystalline silica is not regulated by the U.S. Occupational Safety and Health Administration as a carcinogen. It must be noted that there are other publications that do not agree with view point. Other concerns are auto immune diseases, tuberculosis and kidney disease.

Additional Comments:

Section 12.- Ecological Information

Similar to common sand. Quartz is not known to be ecotoxic, i.e., there is no data which suggests that quartz is toxic to birds, fish, invertebrates, microorganisms or plants.

Additional Comments:

Section 13.- Disposal Considerations

Similar to common silica sand. The green foundry sand from ferrous industry can be landfilled.

Additional Comments:

Section 14.- Transport Information

Crystalline silica (quartz) is not a hazardous material for purposes of transportation under the U.S.Department of Transportation Table of Hazardous Materials 49CFR Section 172.10.

Additional Comments:

Section 15.- Regulatory Information

RCRA: Ferrous foundry sand can be used in flowable fills (40 CFR Part 247)

CERCLA:

Clean Air Act:

TNRCC:

Additional Comments:

Section 16.- Other Information

Hazardous Material Information System (HMIS)/National Fire Protection Association (NFPA)

	Foundry Sand	Silica Sand
Health		Section 11
Flammability		0
Reactivity		0

Additional Comments:

Web Site with Information:

ENGINEERING PROPERTIES #1/ 1-97

1. **INDUSTRY/TYPE OF SAND:-**

   Steel Foundry Casting / Unused (clean) foundry sand (binder: none)

2. **SOURCE (name, location):-**

   Badger Mining Corporation, Wisconsin.

3. **PROPERTIES OF FOUNDRY SAND:-**

   Moisture content (ASTM C 566) : 0.19%
   Unit weight (ASTM C 29): 1,730 kg/m^3
   Apparent specific gravity (ASTM C 128): 2.70
   Absorption (ASTM C 128): 4.9%
   Void Content(ASTM C 29): 33.8%
   Clay lumps and friable particles (ASTM C 142): 0.1%
   Particle size analysis (ASTM C 136): Finer than Sieve No. 50 = 58.5%; Finer than Sieve No. 100 = 3.9%;
   Finer than No. 200 sieve: 0.17%
   Soundness of the aggregates (ASTM C 88): 10.5%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable slurry/Laboratory.

5. **MIXTURE:-** Foundry sand (up to 85% replacement for fly ash), fly ash (Class F) and cement. Water-to-binder ratio varied from 0.48 to 1.25.

6. **TYPES OF TESTS FOR APPLICATIONS:-**

   50 mm nail penetration, bleed water, flowability, plastic shrinkage cracks, unit weight, compressive strength (ASTM D 4832)

7. **PROPERTIES OF MIXTURE:-**

   50-mm nail penetration (Not a ASTM test): 1.5 mm - 50 mm
   Bleed water (Not a ASTM test): 0 - 17.8 mm
   Compressive strength (ASTM D 4832): 0.17 - 0.76 MPa

8. **REMARKS:-**

   (1) Clean FS had lower unit weight and higher water absorption than ASTM C 33 sand; **(2)** FS sand did not meet the ASTM C 33 sand; **(3)** FS can be used as replacement for fly ash in flowable slurry; **(4)** up to 85% fly ash can be replaced with FS in developing flowable fill with 28 day compressive strength in the range of 0.28 to 0.62 MPa (40 -90 psi).

9. **REFERENCES:-**

Naik, T. R. and Singh, S. S. (1997), "Flowable Slurry Containing Foundry Sands," Journal of Materials in Civil Engineering, ASCE, Vol. 9, pp. 93 - 102.

ENGINEERING PROPERTIES # 2 / 1-96

1. **INDUSTRY/TYPE OF SAND:-**
   Metal Foundry Casting / Unused foundry sand (binder: none)

2. **SOURCE (name, location):-**
   Indiana.

3. **PROPERTIES OF FOUNDRY SAND:-**
   Moisture content (ASTM C 566) : Not available
   Unit weight (ASTM C 29):Not available
   Bulk specific gravity (ASTM C 128): 2.66
   Absorption (ASTM C 128): 0.5%
   Void (ASTM C 29): Not available
   Clay lumps and friable particles (ASTM C 142): Not available
   Particle size analysis (ASTM C 136): uniform grading; d_{50} = 0.32 mm.
   Finer than No. 200 sieve (ASTM C 117): Not available
   Soundness of the aggregates (ASTM C 88): 10.5%
   Loss on Ignition (LOI) : 0.1%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable slurry/ Laboratory

5. **MIXTURE:-** Foundry sand (1344, 1318 kg/m^3), fly ash (439, 443 kg/m^3), cement (73, 56) and water-to-cement ratio (5.34, 4.05) mixture

6. **TYPE OF TESTS FOR APPLICATIONS:-**
   Penetration resistance, flowability, Bleeding, Permeability, pH of pore fluid, Toxicity (Bioassay test), compressive strength

7. **PROPERTIES OF MIXTURE:-**
   flowability (ASTM): 230 mm (9 in. spread)
   pH of bleed water (ASTM): not available
   Compressive strength (ASTM): 0.17 - 0.76 MPa
   Toxicity test: not available

8. **REMARKS:-**
   Unused FS can be used in making flowable fill materials without any modification or adjustment.

9. **REFERENCES:-**
   Bhat, S. T. and Lovell, C. W. (1996?) "Design of Flowable Fill: Waste Foundry Sand as a Fine Aggregate," Transport Research Record, Vol. 1546, pp. 70 - 78.

ENGINEERING PROPERTIES # 3 / 2-97

1. **INDUSTRY/TYPE OF SAND:-**
   Steel Foundry Casting / Green foundry sand (binder: bentonite)

2. **SOURCE (name, location):-**
   Maynard Steel Casting Corp., Milwaukee, Wisconsin.

3. **PROPERTIES OF FOUNDRY SAND:-**
   Moisture content (ASTM C 566) : 0.25%
   Unit weight (ASTM C 29): 1,784 kg/m^3
   Apparent specific gravity (ASTM C 128): 2.79
   Absorption (ASTM C 128): 5.0%
   Void Content(ASTM C 29): 34.8%
   Clay lumps and friable particles (ASTM C 142): 0.4%
   Particle size analysis (ASTM C 136): Finer than Sieve No. 50 = 53.4%; Finer than Sieve No. 100 = 6.3%;
   Finer than No. 200 sieve (ASTM C 117): 1.08%
   Soundness of the aggregates (ASTM C 88): 54.9%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable slurry/Laboratory.

5. **MIXTURE:-** Used foundry sand (up to 85% replacement for fly ash), fly ash (Class F) and cement. Water-to-binder ratio varied from 0.48 to 1.25.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
   50 mm nail penetration, bleed water, flowability, plastic shrinkage cracks, unit weight, compressive strength (ASTM D 4832)

7. **PROPERTIES OF MIXTURE:-**
   50-mm nail penetration (Not a ASTM test): 1.5 mm - 50 mm
   Bleed water (Not a ASTM test): 0 - 16.8 mm
   Compressive strength (ASTM D 4832): 0.38 - 0.76 MPa

8. **REMARKS:-**
   (1) Clean FS had lower unit weight and higher water absorption than ASTM C 33 sand; (2) FS sand did not meet the ASTM C 33 sand; (3) can be used as replacement for fly ash in flowable slurry; (4) up to 85% fly ash can be replaced with FS in deveoping flowable fill with 28 day compressive strength in the range of 0.38 to 0.76 MPa (55 - 110 psi).

9. **REFERENCES:-**
   Naik, T. R. and Singh, S. S. (1997), "Flowable Slurry Containing Foundry Sands," Journal of Materials in Civil Engineering, ASCE, Vol. 9, pp. 93 - 102.

ENGINEERING PROPERTIES # 4 / 1-94

1. **INDUSTRY/TYPE OF SAND:-**
Steel Foundry Casting / Clean foundry sand (binder: clay)

2. **SOURCE (name, location):-**
Badger Mining Corp. and Falk Corp., Milwaukee, Wisconsin.

3. **PROPERTIES OF FOUNDRY SAND:-**
   Moisture content (ASTM C 566) : 0.09%
   Unit weight (ASTM C 29): 1,746 kg/m^3
   Bulk specific gravity (ASTM C 127 & 128): 2.58
   Apparent specific gravity (ASTM C 127 & 128): 2.87
   Absorption (ASTM C 127 & 128): 1.25%
   Void Content (ASTM C 29): 33%
   Fineness modulus (ASTM C 136): 2.34
   Clay lumps and friable particles (ASTM C 142): 0.10%
   Finer than No. 200 sieve (ASTM C 117): 0.20%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Concrete/Laboratory.

5. **MIXTURE:-** Cement (362 kg), Used foundry sand (0 - 300 kg), sand (558 - 644 kg). Water-to-binder ratio varied from 0.48.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
Uniaxial compressive strength (ASTM C39), splitting tensile strength (ASTM C496), modulus of elasticity (ASTM C469)

7. **PROPERTIES OF MIXTURE:-**
   Compressive strength: 28.3 - 43.6 MPa
   Tensile strength: 2.1 - 4.0 MPa
   Modulus of elasticity: 20,900 - 33,400 MPa

8. **REMARKS:-**
(1) Physical properties of regular concrete sand and clean/unused FS were compared; (2) clean and used FS had different physical properties such as moisture content, specific gravity, void, fineness and clay lumps; (3) specified design strength of 38 MPa was used; (4) concrete containing up to 35% (by weight) of used FS showed 20 - 30% lower values than regular concrete; (5) compressive strength in the range of 19.9 to 43.8 MPa.

9. **REFERENCES:-**
Naik, T. R., Patel, V. M., Parikh, D. M., Tharaniyil, M. P. (1994), "Utilization of Used Foundry Sand in Concrete," Journal of Materials in Civil Engineering, ASCE, Vol. 6, pp. 254 - 263.

ENGINEERING PROPERTIES # 5 / 2-94

1. **INDUSTRY/TYPE OF SAND:-**
Steel Foundry Casting / Green foundry sand (binder: clay)

2. **SOURCE (name, location):-**
Badger Mining Corp. and Falk Corp., Milwaukee, Wisconsin.

3. **PROPERTIES OF FOUNDRY SAND:-**
   Moisture content (ASTM C 566) : 0.17%
   Unit weight (ASTM C 29): 1,746 kg/m^3
   Bulk specific gravity (ASTM C 127 & 128): 2.37
   Apparent specific gravity (ASTM C 127 & 128): 2.58
   Absorption (ASTM C 127 & 128): 3.4%
   Void Content (ASTM C 29): 26%
   Fineness modulus (ASTM C 136): 2.40
   Clay lumps and friable particles (ASTM C 142): 2.1%
   Finer than No. 200 sieve (ASTM C 117): 2.70%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Concrete/Laboratory.

5. **MIXTURE:-** Cement (362 kg), Used foundry sand (0 - 300 kg), sand (558 - 644 kg). Water-to-binder ratio varied from 0.48.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
Uniaxial compressive strength (ASTM C39), splitting tensile strength (ASTM C496), modulus of elasticity (ASTM C469)

7. **PROPERTIES OF MIXTURE:-**
   Compressive strength: 19.9 - 33.6 MPa
   Tensile strength: 1.8 - 3.6 MPa
   Modulus of elasticity: 18,400 - 32,600 MPa

8. **REMARKS:-**
(1) Physical properties of regular concrete sand and discarded/used FS were compared; (2) clean and used FS had different physical properties such as moisture content, specific gravity, void, fineness and clay lumps; (3) specified design strength of 38 MPa was used; (4) concrete containing up to 35% of used FS showed 20 - 30% lower values than regular concrete; (5) compressive strength in the range of 19.9 to 43.8 MPa.

9. **REFERENCES:-**
Naik, T. R., Patel, V. M., Parikh, D. M., Tharaniyil, M. P. (1994), "Utilization of Used Foundry Sand in Concrete," Journal of Materials in Civil Engineering, ASCE, Vol. 6, pp. 254 - 263.

ENGINEERING PROPERTIES # 6 / 3-97

1. **INDUSTRY/TYPE OF SAND:-**
Steel Foundry Casting / Green foundry sand (binder: clay)

2. **SOURCE (name, location):-**
Not available

3. **PROPERTIES OF FOUNDRY SAND:-**
d_{50}: 0.36 mm
Specific gravity: 2.53
Bulk specific gravity: 2.48
Absorption: 1.5%
Loss on ignition: 3.8%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable fill/Laboratory.

5. **MIXTURE:-** Cement (30-60 kg/m^3), fly ash (86-257 kg/m^3), foundry sand (1242- 1346 kg/m^3). Water-to-cement ratio varied from 6.37-12.5.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
Flow test (ASTM PS 28-95)
Penetration test (ASTM C403)
Unconfined compressive strength (ASTM D 4832)
Permeability (ASTM D5084)
pH

7. **PROPERTIES OF MIXTURE:-**
Bleeding: 1.2 - 3.0%
Compressive strength: 365 - 834 kPa
Permeability: 3.8-4 x 10^{-6} cm/sec
pH: 11.5 - 12.3

8. **REMARKS:-**
(1) Physical properties of regular concrete sand and discarded/used FS were compared;
(2) clean and used FS had different physical properties such as d_{50}, moisture content, specific gravity and loss on ignition;
(3) a water-to-cement ratio of 5.5 to 7.5 is a good start point for flowable fill design test;
(4) specified design strength of 1035 kPa was used;
(5) the pH of the flowable fill is non-corrosive in nature.

9. **REFERENCES:-**
Bhat, S. T. and Lovell C. W. (1997), "Flowable Fill Using Waste Foundry Sand: A Substitute for Compacted or Stabilized Soil," Testing Soil Mixed with Waste or Recycled Materials, ASTM STP 1275, pp 26 - 41.

ENGINEERING PROPERTIES # 7 / 4-97

1. **INDUSTRY/TYPE OF SAND:-**
   Steel Foundry Casting / Green foundry sand (binder: clay)

2. **SOURCE (name, location):-**
   Not available

3. **PROPERTIES OF FOUNDRY SAND:-**
   d_{50}: 0.39 mm
   Specific gravity: 2.42
   Bulk specific gravity: 2.25
   Absorption: 5.5%
   Loss on ignition: 7.8%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable fill/Laboratory.

5. **MIXTURE:-** Cement (50-70 kg/m^3), fly ash (258-361 kg/m^3), foundry sand (963- 1032 kg/m^3). Water-to-cement ratio varied from 5.76-8.56.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
   Flow test (ASTM PS 28-95)
   Penetration test (ASTM C403)
   Unconfined compressive strength (ASTM D 4832)
   Permeability (ASTM D5084)
   pH

7. **PROPERTIES OF MIXTURE:-**
   Bleeding: 1.3 - 2.1%
   Compressive strength: 545 - 1048 kPa
   Permeability: 6.7-12 x 10^{-6} cm/sec
   pH: 11.4 - 11.8

8. **REMARKS:-**
   (1) Physical properties of regular concrete sand and discarded/used FS were compared;
   (2) clean and used FS had different physical properties such as d_{50}, moisture content, specific gravity and loss on ignition;
   (3) a water-to-cement ratio of 5.5 to 7.5 is a good start point for flowable fill design test;
   (4) specified design strength of 1035 kPa was used;
   (5) the pH of the flowable fill is non-corrosive in nature.

9. **REFERENCES:-**
   Bhat, S. T. and Lovell C. W. (1997), "Flowable Fill Using Waste Foundry Sand: A Substitute for Compacted or Stabilized Soil," Testing Soil Mixed with Waste or Recycled Materials, ASTM STP 1275, pp 26 - 41.

ENGINEERING PROPERTIES # 8/ 5-97

1. **INDUSTRY/TYPE OF SAND:-**
Steel Foundry Casting / Green foundry sand (binder: clay)

2. **SOURCE (name, location):-**
Not available

3. **PROPERTIES OF FOUNDRY SAND:-**
d_{50}: 0.26 mm
Specific gravity: 2.50
Bulk specific gravity: 2.45
Absorption: 1.6%
Loss on ignition: 2.1%

4. **APPLICATION/LABORATORY OR FIELD STUDY:-** Flowable fill/Laboratory.

5. **MIXTURE:-** Cement (35-50 kg/m^3), fly ash (55-409 kg/m^3), foundry sand (1041- 1322 kg/m^3). Water-to-cement ratio varied from 8.18-11.2.

6. **TYPES OF TESTS FOR APPLICATIONS:-**
Flow test (ASTM PS 28-95)
Penetration test (ASTM C403)
Unconfined compressive strength (ASTM D 4832)
Permeability (ASTM D5084)
pH

7. **PROPERTIES OF MIXTURE:-**
Bleeding: 4.1 - 4.8%
Compressive strength: 365 - 717 kPa
Permeability: 1.1-1.9 x 10^{-5} cm/sec
pH: 11.4 - 11.8

8. **REMARKS:-**
(1) Physical properties of regular concrete sand and discarded/used FS were compared;
(2) clean and used FS had different physical properties such as d_{50}, moisture content, specific gravity and loss on ignition;
(3) a water-to-cement ratio of 5.5 to 7.5 is a good start point for flowable fill design test;
(4) partial replacement fly ash with used FS in flowable fill reduced compressive strength by 20 - 30%;
(5) compressive strength in the range of 19.9 to 43.8 MPa.
(6) the pH of the flowable fill is non-corrosive in nature.

9. **REFERENCES:-**
Bhat, S. T. and Lovell C. W. (1997), "Flowable Fill Using Waste Foundry Sand: A Substitute for Compacted or Stabilized Soil," Testing Soil Mixed with Waste or Recycled Materials, ASTM STP 1275, pp 26 - 41.

ENGINEERING PROPERTIES # 9 / 1-98

1. **INDUSTRY/TYPE OF SAND:-**
   Steel Foundry Casting / Green foundry sand (binder: Bentonite clay)

2. **SOURCE (name, location):-**
   A green sand foundry in Wisconsin

3. **PROPERTIES OF FOUNDRY SAND:-**
   Not available

4. **APPLICATION/LABORATORY OR FIELD STUDY:-**
   Hydraulic barrier//Field and Laboratory.

5. **MIXTURE:-** Green sand

6. **TYPES OF TESTS FOR APPLICATIONS:-**
   Liquid and plastic limits (ASTM D 4318)
   Particle size (ASTM D 422)
   Compaction (ASTM D 698 and D 1557)
   Hydraulic conductivity (ASTM D 5084)
   Freeze-thaw testing (ASTM D 6035)
   Desiccation (ASTM D 5084)

7. **PROPERTIES OF MIXTURE:-**
   Liquid limit: 27
   Plasticity index: 8
   Fines content: 12.1%
   Bentonite content: 8.5%
   Dry unit weight: 16 to 18.2 kN/m^3 for water content 7.5 to 22%
   Hydraulic conductivity: 2.3-25 x 10^{-9} cm/sec
   Freeze-thaw testing, Kr: 0.7 to 1.2
   Desiccation, Kr: 0.45 to 3.5

8. **REMARKS:-**
   (1) Wisconsin foundries generate about 800,000 kg of by-products per year;
   (2) engineering properties of sand was not given;
   (3) a hydraulic conductivity of 1x10^{-7} cm/sec was selected as standard for hydraulic barrier;
   (4) laboratory and field studies were conducted;
   (5) green sand can be compacted to very low hydraulic conductivity (10^{-9} to 10^{-8} cm/sec) using a broad range of compactive efforts;
   (6) hydraulic barrier constructed using green sand was not affected by freeze-thaw and desiccation conditions;
   (7) field and laboratory hydraulic conductivity tests were closed.

9. **REFERENCES:-**
Abichou, T., Benson, C. H., Edil, T. B., and Freber, W. (1998), "Using Waste Foundry Sand for Hydraulic Barriers," Proceedings of the Geo-Congress: Recycled Materials in Geotechnical Applications, Boston, MA, Oct. 18-21, 1998, pp 86-99.

FOUNDRY SAND ENVIRONMENTAL PROPERTIES - #1/1-96

1. **MATERIAL PROCESS:-**

   Sand, slag, and baghouse dust

2. **LOCATION AND AMOUNT OF FS :-**

   300,000 tons per year in Pennsylvania (estimated to have 37 foundries)

3. **TYPE OF TESTS:-**

   Toxicity Characteristic Leaching Procedure (EPA Method 1311)

   Synthetic Precipitation Leaching Procedure (EPA Method 1312)

4. **CONTAMINANTS:-**

INORGANICS:-	Al, Sb, As, Ba, Cd, Cr (total), Cr(VI), Cu, cyanide (total), F, Fe, Pb, Mn, Hg, Mb, Ni, Se, Ag, Zn
pH Range	5.5 to 9.5
ORGANICS:-	Benzene, Benzoic acid, Ethylene, Naphthalene, Petroleum hydrocarbons, Phenanthrene, Phenol(s), Resorcinol, Toluene, Total organic halogens, 1,2,4-Trimethylbenzene, Xylene

5. **STANDARD OR RELATED REGULATION:-**

Pennsylvania Foundryman's Association (PFA) with Pennsylvania Department of Environmental Protection (PaDEP) has developed standards which establishes the **total levels** (mg/kg) and **leachable levels** (mg/L) for the metals and organics listed in Section 4. According to the permit condition the sand "shall no be used in roadway construction or otherwise placed directly into the environment if any of the total or leachable levels are reached. Leachable levels are determined using the TCLP or EPA Method 1312.

6. **REMARKS:-**

   Specifies the testing methods and the limits on total levels and leachable levels for various metals and organics in the foundry sands.

7. **REFERENCES:-**

Regan R. W. and Voigt R. C. (1996) "Beneficial Use of Foundry Solid Wastes: Working with the Regulators," Proceedings of 19th International Madison Waste Conference, September 25-26, 1996, Madison, WI.

FOUNDRY SAND ENVIRONMENTAL PROPERTIES - #2/ 1-81

1. **MATERIAL PROCESS:-**

   Various core and system sands from foundry industry

2. **LOCATION AND AMOUNT OF FS :-**

   Not available (laboratory synthetic foundry sands)

3. **TYPE OF TESTS:-**

   Shake-flask technique (not standard test method)

4. **CONCERNED CONTAMINANTS:-**

   INORGANICS:- Na, Al, Fe, Cu, Zn, P, K, Ca, Mg, Ba, Sr, B, Mn, Cr

   ORGANICS:- Phenol, COD, BOD

5. **STANDARD OR RELATED REGULATION:-**

   Not available

6. **REMARKS:-**

   The shake-flask technique can be used to obtain apparent maximum release of matter from foundry sand under conditions of continuous sand-water contact.

7. **REFERENCES:-**

   Ham, R. K., Boyle, W. C., Kunes, T. P. (1981) "Leachability of Foundry Process Solid Wastes," Journal of Environmental Engineering, Vol. 107, pp. 155 - 170

FOUNDRY SAND ENVIRONMENTAL PROPERTIES - #3/ 1-92

1. **MATERIAL PROCESS:-**

   Waste foundry sands

2. **LOCATION AND AMOUNT OF FS :-**

   West Germany; annual waste: 2 million tons/year

3. **TYPE OF TESTS:-**

   Shake-flask technique (not standard test method)

4. **CONCERNED CONTAMINANTS:-**

   INORGANICS:- Na, Al, Fe, Cu, Zn, P, K, Ca, Mg, Ba, Sr, B, Mn, Cr

   ORGANICS:- Phenol, COD, BOD

5. **STANDARD OR RELATED REGULATION:-**

   Not available

6. **REMARKS:-**

   The shake-flask technique can be used to obtain apparent maximum release of matter from foundry sand under conditions of continuous sand-water contact.

7. **REFERENCES:-**

   Lahl, U. (1992) "Recycling of Waste Foundry Sands," The Science fo Total Environment, Vol. 114, pp. 185 - 193

FOUNDRY SAND ENVIRONMENTAL PROPERTIES - #4 / 1-97

1. **INDUSTRY/TYPE OF SAND:-**
   Steel Foundry Casting / Green foundry sand (binder: bentonite)

2. **SOURCE (name, location):-**
   Maynard Steel Casting Corp., Milwaukee, Wisconsin.

3. **TYPE OF TESTS:-**
   Toxicity Characteristic Leaching Procedure (EPA Method 1311)
   Synthetic Precipitation Leaching Procedure (EPA Method 1312)

4. **CONCERNED CONTAMINANTS:-**

   INORGANICS:- Ti (546 ppm), Mg (490 ppm), Si (44,800 ppm), Al (601 ppm), Cr (3,570 ppm), Zr (6,880 ppm), Na (1,280 ppm) and Fe (3, 056 ppm)

   ORGANICS:- Not available

5. **STANDARD OR RELATED REGULATION:-**
   Not available

6. **REMARKS:-**

7. **REFERENCES:-**
   Naik, T. R. and Singh, S. S. (1997), "Flowable Slurry Containing Foundry Sands," Journal of Materials in Civil Engineering, ASCE, Vol. 9, pp. 93 - 102.

Federal Register

Wednesday,
January 19, 2000

Part V

Environmental Protection Agency

40 CFR Part 247

Comprehensive Guideline for Procurement of Products Containing Recovered Materials; Recovered Materials Advisory Notice III; Final Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 247

[SWH–FRL–6524–2]

RIN 2050–AE23

Comprehensive Guideline for Procurement of Products Containing Recovered Materials

AGENCY: Environmental Protection Agency.

ACTION: Final rule.

SUMMARY: The Environmental Protection Agency today is amending the May 1, 1995 Comprehensive Procurement Guideline (CPG). EPA is designating 18 new items that are or can be made with recovered materials. These items are carpet cushion; flowable fill; railroad grade crossing surfaces; park benches and picnic tables; playground equipment; food waste compost; plastic lumber landscaping timbers and posts; solid plastic binders; plastic clipboards; plastic file folders; plastic clip portfolios; plastic presentation folders; sorbents (i.e., absorbents and adsorbents); industrial drums; awards and plaques; mats; signage; and manual-grade strapping.

The CPG implements section 6002 of the Resource Conservation and Recovery Act (RCRA) and section 502 of Executive Order 13101, which require EPA to designate items that are or can be made with recovered materials and to recommend practices that procuring agencies can use to procure designated items. Once EPA designates an item, any procuring agency that uses appropriated Federal funds to procure that item must purchase the item containing the highest percentage of recovered materials practicable. Today's action will use government purchasing power to stimulate the use of these materials in the manufacture of new products, thereby, fostering markets for materials recovered from solid waste.

RCRA section 6002 provides certain limited exceptions to the general requirement to buy EPA-designated items. Under certain circumstances based on competition, price, availability, and performance, RCRA section 6002 does not require that procuring agencies purchase an item designated by EPA. In the May 1, 1995 CPG, EPA codified the RCRA section 6002 procurement requirements for the convenience of procuring agencies so they could find all of the RCRA section 6002 procurement provisions, as well as EPA's item designations, in one location. You can find these requirements at 40 CFR Part 247.

EFFECTIVE DATE: This final rule is effective on January 19, 2001.

ADDRESSES: The public docket for this document is Docket F–1999–CP3F–FFFFF. Documents related to today's notice are available for viewing in the RCRA Information Center (RIC), which is located at U.S. Environmental Protection Agency, Crystal Gateway One, 1235 Jefferson Davis Highway, Ground Floor, Arlington, VA 22202. The RIC is open from 9 a.m. to 4 p.m., Monday through Friday, except for Federal holidays. To review docket materials, it is recommended that the public make an appointment by calling (703) 603–9230. Copies cost $0.15/page. The index and some supporting materials are available electronically. See Section IX of the "Supplementary Information" section below for information on accessing the documents electronically.

FOR FURTHER INFORMATION CONTACT: For general information contact the RCRA Hotline at (800) 424–9346 or TDD (800) 553–7672 (hearing impaired). In the Washington, DC metropolitan area, call (703) 412–9810 or TDD (703) 412–3323. For technical information on individual item designations, contact Terry Grist at (703) 308–7257.

SUPPLEMENTARY INFORMATION:

Preamble Outline

I. What Is the Statutory Authority for This Amendment?

EPA ("the Agency") is promulgating this amendment to the Comprehensive Procurement Guideline under the authority of sections 2002(a) and 6002 of the Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended, 42 U.S.C. 6912(a) and 6962. The Agency is also promulgating this amendment under section 502 of Executive Order (E.O.) 13101, "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition," (63 FR 49643, September 14, 1998).

II. Who Is Affected by This Amendment?

This action may potentially affect procuring agencies that purchase the following items: carpet cushion; flowable fill; railroad grade crossing surfaces; park benches and picnic tables; playground equipment; food waste compost; plastic lumber landscaping timbers and posts; solid plastic binders; plastic clipboards; plastic file folders; plastic clip portfolios; plastic presentation folders; sorbents (i.e., absorbents and adsorbents); awards and plaques; industrial drums; mats; signage; and manual-grade strapping. Under RCRA section 6002, procuring agencies include the following: (1) Any Federal agency; (2) any State or local agency using appropriated Federal funds for a procurement; or (3) any contractors of these agencies who are procuring these items for work they perform under the contract. See RCRA section 1004(17). The requirements of section 6002 apply to these procuring agencies only when the agencies procure designated items whose price exceeds $10,000 or when the quantity of the item purchased in the previous year exceeded $10,000. A list of entities that this rule may cover is provided in Table 1.

TABLE 1.—ENTITIES POTENTIALLY SUBJECT TO SECTION 6002 REQUIREMENTS TRIGGERED BY CPG AMENDMENTS

Category	Examples of regulated entities
Federal Government	Federal departments or agencies that procure $10,000 or more of a designated item in a given year.
State Government	A State agency that uses appropriated Federal funds to procure $10,000 or more of a designated item in a given year.
Local Government	A local agency that uses appropriated Federal funds to procure $10,000 or more of a designated item in a given year.
Contractor	A contractor working on a project funded by appropriated Federal funds that purchases $10,000 or more of a designated item in a given year.

This table is not intended to be exhaustive. To determine whether this action applies to your procurement practices, you should carefully examine the applicability criteria in 40 CFR § 247.12. If you have questions about whether this action applies to a particular entity, contact Terry Grist at (703) 308–7257.

RCRA section 6002 applies to procuring agencies that use at least a portion of Federal funds to procure over $10,000 worth of a designated product in a given year. EPA estimates that this rule would apply to 35 Federal agencies, all 56 states and territories and 1,900 local governments. EPA calculated the number of local governments that would be impacted by this rule based on information on the amount of Federal funds that are dispersed to specific counties. In addition, EPA assumed that 1,000 contractors may be affected. A description of this information is provided in the Economic Impact Analysis for today's rule.

III. Why Is EPA Taking This Action?

Section 6002(e) of RCRA requires EPA to designate items that are or can be made with recovered materials and to recommend practices to help procuring agencies meet their obligations for procuring items designated under RCRA section 6002. RCRA requires that when a procuring agency purchase an EPA-designated item, the agency must purchase that item made of the highest percentage of recovered materials practicable.

E.O. 13101 establishes the procedures EPA must follow when implementing RCRA section 6002(e). Section 502 of the Executive Order directs EPA to issue a Comprehensive Procurement Guideline (CPG) that designates items that are or can be made with recovered materials. At the same time EPA promulgates the CPG, the Agency must publish its recommended procurement practices for entities that purchase designated items in a related Recovered Materials Advisory Notice (RMAN). These practices must also provide recommendations for the content of recovered materials in the designated items. The Executive Order also directs EPA to update the CPG every two years and to issue RMANs periodically to reflect changing market conditions.

The original CPG (CPG I) was published on May 1, 1995 (60 FR 21370). It established eight product categories, designated 19 new items, and consolidated five earlier item designations. At the same time, EPA published the first RMAN (RMAN I) (60 FR 21386). On November 13, 1997, EPA published CPG II (62 FR 60962), which designated an additional 12 items. At the same time, EPA published a RMAN II (62 FR 60975). Paper Products RMANs were issued on May 29, 1996 (61 FR 26985) and June 8, 1998 (63 FR 31214).

On August 26, 1998, EPA proposed to designate 19 additional items (CPG III) and published draft recommendations that provided recommendations for entities to use when purchasing items that contain recovered materials (RMAN III). See 63 FR 45558–45578 and 63 FR 45580–45589, respectively. Today, EPA is designating 18 of the items proposed in CPG III. In CPG III, EPA proposed designating nylon carpet with backing containing recovered materials, but the Agency is not designating this item, at this time for the reasons explained below. The 18 newly designated items are listed below by product category.

Construction Products

Carpet cushion
Flowable fill
Railroad grade crossing surfaces

Park and Recreation Products

Park benches and picnic tables
Playground equipment

Landscaping Products

Food waste compost
Plastic lumber landscaping timbers and posts

Non-Paper Office Products

Solid plastic binders
Plastic clipboards
Plastic file folders
Plastic clip portfolios
Plastic presentation folders

Miscellaneous

Sorbents
Industrial drums
Awards and plaques
Mats
Signage, including sign supports and posts
Manual-grade strapping

IV. What Criteria Did EPA Use To Select Items for Designation?

RCRA section 6002(e) requires EPA to consider the following when determining which items it will designate:

(1) Availability of the item;
(2) Potential impact of the procurement of the item by procuring agencies on the solid waste stream;
(3) Economic and technological feasibility of producing the item; and
(4) Other uses for the recovered materials used to produce the item.

The Agency also considers other factors in its selection criteria. EPA consulted with Federal procurement and requirements officials to identify other criteria to consider when selecting items for designation. Based on these discussions, the Agency concluded that the limitations set forth in RCRA section 6002(c) should also be factored into its selection decisions. This provision requires that each procuring agency that procures an item that EPA has designated procure the item that contains the highest percentage of recovered materials practicable, while maintaining a satisfactory level of competition. A procuring agency, however, may decide not to procure an EPA-designated item containing recovered materials if the procuring agency determines: (1) The item is not available within a reasonable period of time; (2) the item fails to meet the performance standards that the procuring agency has set forth in the product specifications; or (3) the item is available only at an unreasonable price.

EPA recognized that these criteria could provide procuring agencies with a rationale for not purchasing EPA-designated items that contain recovered materials. For this reason, EPA considers the limitations cited in RCRA section 6002(c) when it selects items to designate in the CPG. Therefore, in CPG I, the Agency outlined the following criteria that it uses when it selects items for designation:

• Use of materials found in solid waste,

• Economic and technological feasibility and performance,

• Impact of government procurement,

• Availability and competition, and

• Other uses for recovered materials.

EPA discussed these criteria in the CPG I background documents and repeated that discussion, for reader convenience, in Section II of the document entitled, "Proposed Comprehensive Procurement Guideline (CPG) III and Draft Recovered Materials Advisory Notice (RMAN) III—Supporting Analyses." The RCRA public docket for the proposed CPG III rule, docket F–1998–CP3P–FFFFF contains this document.

In CPG I, EPA stated that it had adopted two approaches for designating items that are made with recovered materials. For some items, such as floor tiles, the Agency designated *broad* categories and provided information in the RMAN about the appropriate applications or uses for the items. For other items, such as plastic trash bags, EPA designated *specific* items, and, in some instances, specified the types of recovered materials or applications to which the designation applies. The Agency explained the approaches that it took to designate items in the preamble to CPG I (60 FR 21373, May 1, 1995), and repeats them here for the convenience of the reader:

EPA sometimes had information on the availability of a particular item made with a specific recovered material (e.g., plastic), but no information on the availability of the item made from a different recovered material or any indication that it is possible to make the item with a different recovered material. In these instances, EPA concluded that it was appropriate to include the specific material in the item designation in order to provide vital information to procuring agencies as they seek to fulfill their obligations to purchase designated items composed of the highest percentage of recovered materials practicable. This information enables the agencies to focus their efforts on products that are currently available for purchase, reducing their administrative burden. EPA also included information in the proposed CPG, as well as in the draft RMAN that accompanied the proposed CPG, that advised procuring agencies that EPA is not recommending the purchase of an item made from one particular material over a similar item made from another material. For example, EPA included the following statement in the preamble discussion for plastic desktop accessories (59 FR 18879, April 20, 1994): "This designation does not preclude a procuring agency from purchasing desktop accessories manufactured from another material, such as wood. It simply requires that a procuring agency, when purchasing plastic desktop accessories, purchase these accessories made with recovered materials * * *"

The Agency understands that some procuring agencies may believe that designating a broad category of items in the CPG requires that they (1) procure all items included in such category with recovered materials content and (2) establish an affirmative procurement program for the entire category of items, even when specific items within the category do not meet the procuring agency's performance standards. RCRA clearly does not require such actions, as implemented through the CPG and the RMAN. RCRA section 6002 does not require a procuring agency to purchase items that contain recovered materials if the items are not available or if they do not meet a procuring agency's specifications or reasonable performance standards for the contemplated use. Further, section 6002 does not require a procuring agency to purchase such items if the item that contains recovered material is only available at an unreasonable price, or if purchasing such item does not maintain a reasonable level of competition. However, EPA stresses that, the procuring agency should seek to purchase the product made with highest percentage of recovered materials practicable if that product meets the procuring agency's performance requirements and all other factors are equal.

The items designated today have all been evaluated against EPA's criteria. The Agency discusses these evaluations in the "Background Document for the Final Comprehensive Procurement Guideline (CPG) III and Final Recovered Materials Advisory Notice (RMAN) III" (hereafter referred to as the "Background Document for the Final CPG III/RMAN III)," which the Agency has placed in the docket for the final CPG III and RMAN III. You can also access the document electronically. (See Section IX below for Internet access directions.)

V. What Are the Definitions of Terms Used in Today's Action?

Today, in 40 CFR 247.3, EPA is defining the following new item-specific terms: carpet cushion; flowable fill; railroad grade crossing surfaces; park benches and picnic tables; playground equipment; food waste compost; plastic lumber landscaping timbers and posts; solid plastic binders; plastic clipboards; plastic file folders; plastic clip portfolios; plastic presentation folders; sorbents; industrial drums; awards and plaques; mats; signage; and manual-grade strapping. These definitions are based on industry definitions, such as the American Society for Testing and Materials (ASTM) or other industry standards, or describe the scope of items that the Agency is designating.

For several items that the Agency is designating today, EPA recommends in the final RMAN III that procuring agencies use two different measures of the content of recovered materials: (1) A component of postconsumer recovered materials and (2) a component of total recovered materials. In these instances, EPA found that manufacturers were using both types of materials to manufacture the products. If the Agency recommended only postconsumer content levels, it would fail to meet the RCRA mandate to maximize the use of recovered materials, because the Agency would fail to acknowledge the contribution that manufacturers using other manufacturers' byproducts as feedstock have made to solid waste management.

Because the recommendations for the items that the Agency is designating today use the terms "postconsumer materials" and "recovered materials," we repeat the definitions for these terms in this notice. The Agency provided these definitions in CPG I, and they are also provided at 40 CFR 247.3.

Postconsumer materials means a material or finished product that has served its intended end use and has been diverted or recovered from waste destined for disposal, having completed its life as a consumer item. *Postconsumer material* is part of the broader category of recovered materials.

Recovered materials means waste materials and byproducts which have been recovered or diverted from solid waste, but the term does not include those materials and byproducts generated from, and commonly reused within, an original manufacturing process.

VI. What Did Commenters Say About the Proposed CPG III and Draft RMAN III?

Forty commenters responded to the proposed CPG III and the draft RMAN III. These commenters represented various interests, including but not limited to Federal agencies, State agencies, local governments, product manufacturers, trade associations and product users.

In this section, EPA discusses the major comments that commenters provided on the proposed CPG III. The most significant comments received on the draft RMAN III are discussed in the preamble to the notice of availability of the final RMAN III, which is published in the notices section of today's **Federal Register**. You can find a summary of all comments and EPA's responses in the "Background Document for the Final CPG III/RMAN III."

A. General Comments

1. Recordkeeping and Reporting

Comment: The U.S. Department of Energy (DOE) stated that it supports efforts to conserve resources by procuring products containing recovered materials. DOE stated that it has aggressively instituted an affirmative procurement program (APP) throughout the Department. DOE expressed its concern, however, that as the number of designated items increases, administrative costs of the program will become increasingly burdensome. DOE believes that as the reporting and data collection requirements continue to grow with additional designations, it is likely that the good will and positive environmental message of E.O. 13101 will be misplaced. DOE suggested that EPA seek to revise the Federal Acquisition Regulation (FAR) to channel federal purchasing toward products with recycled content. This way, federal agencies could report progress in implementing the FAR language, as opposed to attempting to capture every purchase made by the federal government.

Response: EPA has stated on many occasions that implementation of RCRA section 6002 must be consistent with other federal procurement law. For example, in Appendix II to the "Background Document for Proposed Comprehensive Procurement Guideline (CPG) III and Draft Recovered Materials Advisory Notice (RMAN) III," April 1998, EPA stated the following:

> The purchase of recycled products under RCRA section 6002 must be consistent with other Federal procurement law, which requires that contracts be awarded to the lowest priced, responsive, responsible bidder * * *.
>
> On August 22, 1997, the Civilian Agency Acquisition Council (CAAC) and the Defense Acquisition Regulations Council (DARC) issued a final rule amending the Federal Acquisition Regulation (FAR) parts 1, 10, 11, 13, 15, 23, 36, 42, and 52 to reflect the government's preference for the acquisition of environmentally-sound and energy-efficient products and services and to establish an affirmative procurement program favoring items containing the maximum practicable content of recovered materials. (See 62 FR 44809, August 22, 1997.)

On September 23, 1999, the CAAC and DARC proposed amendments to the FAR to clarify language relating to implementation of Executive Order 13101. The proposed rule (64 FR 51656, September 23, 1999) also reorganizes various sections of the FAR to make environmental procurement policies easier to find and implement. Procuring agencies should consult the FAR for guidance on acquisitions issues.

In addition, the Office of the Federal Environmental Executive has established a Reporting Workgroup and associated subcommittees to examine issues on recordkeeping and reporting. Topics of discussion have included the potential for using automated systems and electronic commerce, vendor reporting, as well as other alternatives. It is the intent of these efforts that, through the use of interagency workgroups, reporting and recordkeeping requirements can be effectively and efficiently implemented. Presumably, if these workgroups determine that additional FAR changes are warranted, these changes could be proposed through the process and procedures already established for amending the FAR.

2. Designation of Materials

Comment: The Steel Recycling Institute (SRI) and the Steel Manufacturers Association submitted separate comments in support of EPA's proposed designation of items containing recovered steel (i.e., railroad grade crossing surfaces, park benches and picnic tables, playground equipment, industrial drums, signage, and strapping). SRI also urged EPA to recognize (i.e., designate) steel in general for its high recyclability and guaranteed recycled content. The American Iron and Steel Institute and the American Zinc Association also submitted comments endorsing the comments provided by SRI.

SRI provided updated information for use in the "Summary of Benefits" section of this notice, stating that its latest study shows that for every ton of steel recycled, 1,400 pounds of coal and 120 pounds of limestone are saved, versus 1,000 pounds of coal and 40 pounds of limestone stated in EPA's notice (63 FR 45575).

SRI also submitted comments on the recycled content of steel products. A summary of these comments and the Agency's response is discussed in RMAN III which is published in the notices section of today's **Federal Register**.

Response: EPA agrees that steel, like many metals, is both recyclable and can contain recovered materials. EPA also agrees that steel, like many metals, is a waste management success story in terms of its recyclability, high recycling rate, and recovered materials content. EPA also applauds the steel industry's source reduction efforts to produce stronger, lighter weight steel, in response to customer demand. RCRA, however, specifically requires EPA to designate items that are or can be made with recovered materials, not the component materials used in those items. Accordingly, EPA designates items that are manufactured with steel, not the material itself.

EPA has used the new data provided by SRI for coal and limestone savings resulting from the use of recovered steel in manufacturing. This information has been incorporated in all applicable documents supporting the final CPG/RMAN III.

B. Comments on Proposed Item Designations

A vast majority of commenters supported the item designations proposed in CPG III with minor comments. This section discusses the major comments submitted on specific items proposed for designation in the proposed CPG III. EPA has included a summary of all comments on the proposed CPG III and our responses in the "Background Document for the Final CPG III/RMAN III." EPA received significant comments on four items: carpet backing, flowable fill, railroad grade crossings, and sorbents. These comments are discussed below. Based on the item-specific comments received, we are promulgating all of the items proposed with the exception of nylon carpet with backing containing recovered materials.

1. Nylon Carpet With Backing Containing Recovered Materials

Comments: EPA received six comments in opposition to the proposed designation of nylon carpet with backing containing recovered materials. These commenters all stated that there is only one manufacturer currently making nylon carpet backing with recovered materials content. They indicated that the manufacturer uses a patented process and, therefore, a designation is premature and does not meet the statutory requirements for adequate competition when designating items.

Response: EPA proposed to designate nylon carpet with backing containing recovered materials based on the fact that at the time of the proposal, one manufacturer was producing carpet tiles with backing containing recovered materials commercially and, as the Agency stated in the background document, two other manufacturers were piloting production runs with recovered materials content and were expected to enter the marketplace. As a result of this comment, EPA conducted additional research and found that, since the proposal, significant developments have occurred in the carpet industry with respect to the use of recovered materials in nylon carpet backing and the fiber facing. As an example, one company is currently making "renewed" carpet tiles. The company takes old carpet and makes renewed carpet tiles through a series of process steps which include supercleaning, retexturing of fibers, and adding colors and patterns. In addition, many companies have begun or are expected to begin manufacturing nylon carpet tiles with recovered materials in the fiber facing. Since significant developments have occurred with respect to the use of recovered materials in the nylon carpet industry, the Agency believes additional research should be conducted before a final designation for nylon carpet or nylon carpet backing is issued to ensure these developments are given proper consideration. Therefore, the Agency is not designating this item at this time, but will consider designating nylon carpet products when proposing the next procurement guideline (CPG IV).

Although the Agency is not designating this item at this time, procuring agencies may choose to procure any item containing recovered materials, regardless of whether the item is specifically designated by EPA. Procurement of items containing recovered materials, whether or not they are designated by EPA, is consistent with RCRA section 6002 and E.O. 13101.

2. Flowable Fill

EPA received 18 sets of comments on its proposal to designate flowable fill containing coal fly ash and ferrous foundry sands. While all commenters supported the proposed designation for flowable fill containing coal fly ash, some commenters raised issues on the proposed designation of flowable fill containing ferrous foundry sands. The following discussions summarize these concerns and other issues raised by the commenters and also provides the Agency's response.

Comment: The FIRST Project (Foundry Industry Recycling Starts Today), which is an industry consortium, supported EPA's designation of flowable fill containing foundry sand, with a few comments. The FIRST Project took issue with EPA's statement that nonferrous foundry sands are typically hazardous waste due to their lead and cadmium content (63 FR 45563). The FIRST Project maintains that spent sand from the vast majority of nonferrous foundries is not hazardous, nor does it contain lead and cadmium. The FIRST Project provided analytical data from nonferrous foundry sand samples to support their position. According to the FIRST Project, due to changes in alloy chemistries of many nonferrous foundry operations over the past decade, spent sands meet EPA and state definitions of nonhazardous waste. The FIRST Project requested that EPA correct the statement about nonferrous sands being hazardous waste. They also suggested that EPA list the American Foundrymen's Society as another resource for obtaining information on the use of spent foundry sand in flowable fill.

Response: EPA based its statement regarding the hazardousness of nonferrous foundry sands on industry data provided to the Agency in 1995 as part of the Phase IV Land Disposal Restrictions (LDR) rulemaking (60 FR 43654, August 22, 1995). These data indicated that the sands from 98% of bronze and brass (B&B) foundries and 40% of bronze and brass and aluminum (B&B&A) foundries were characteristically hazardous for metals.

The commenter's analytical data do not support their claim that a majority of nonferrous foundry sands are nonhazardous because in numerous cases, improper test methods were used. First, for 8 of 12 aluminum green sand waste samples, the digestion of the sample uses SW–846 Method 3010A or Method 3020A (both normally used for water) instead of Methods 3050 and 3051 (both used for solids). (The other 4 aluminum green sand samples did use Method 3051.) These digestion methods are weaker and would extract less of whatever metals are present in the waste matrix. In addition, virtually all of the commenter's leachate extraction data on spent sand waste samples were done using either the Synthetic Precipitation Leaching Procedure (SPLP) SW–846 Method 1312 (which relies on nitric/sulphuric acid as the extractant or deionized water) rather than the Toxicity Characteristic Leachate Procedure (TCLP) SW–846 Method 1311 which the Agency uses to determine toxicity for purposes of assessing hazardousness under 40 CFR 261.24. Therefore, the commenter's leachate extraction data are not appropriate for determining whether the samples tested are characteristically hazardous.

The Agency agrees with the commenter, however, that the statement in the proposed CPG III was too general and may have implied a conclusive determination about the regulatory nature of nonferrous foundry sands. This clearly was not the intent of the statement. Therefore, the Agency has removed any characterization of nonferrous foundry sands as hazardous in the final CPG III and all supporting documents.

The Agency agrees with the commenter that the American Foundrymen's Society should be identified as a resource for obtaining information regarding the use of spent foundry sand in flowable fill and EPA will ensure this reference is made in all documents supporting the final CPG III/RMAN III where appropriate.

Comment: The FIRST Project commented that applications for the use of flowable fill should be broadened to include structural fill for foundation subbases, subfootings, floor lab bases, and pipe beddings.

Response: EPA's designation in the CPG and recommendations in the RMAN do not preclude procuring agencies from using flowable fill in the applications suggested by the commenter. If flowable fill meets the requisite specifications and performance standards for a particular application, then flowable fill can be considered for use by a procuring agency. The specifications and test methods identified in the RMAN are provided to help procuring agencies in their procurement efforts. If a procuring Agency wants to include other applications for flowable fill in their affirmative procurement program (APP), it can exercise its discretion in doing so without being restricted to the applications recommended by EPA in the RMAN. EPA is required to revise the RMAN recommendations periodically and will consider the applications suggested by the commenter in future revisions. However, any recommendations made by EPA, will be subject to notice and public comment. EPA requests that commenters provide any pertinent information on the suggested applications, including references to any industry specifications and test methods appropriate for the various applications. We will consider all information received on this matter when we update the RMAN recommendations.

Comment: The Federal Highway Administration (FHWA) submitted comments stating its concern that, based on one of its user guidelines, there might be a problem with foundry sand stockpile water being contaminated with phenols and, that if this is the case, there would be a discrepancy between this and the CPG statement that ferrous foundry sands are not known to be a hazardous waste. They provided no information or analytical data to substantiate their statement. FHWA requested that this issue be addressed since they could not support this designation if it placed an undue burden on state departments of transportation to monitor each site or if it requires mitigation by contractors.

Response: EPA is aware that phenols may be present in some ferrous foundry sands. According to a 1989 study sponsored by the American Foundrymen's Society and conducted by the University of Wisconsin, phenols were present in some ferrous foundry sands well below regulatory levels, so the Agency does not believe there is reason for concern. In addition, the designation of flowable fill containing ferrous foundry sands in the CPG does not exempt these sands from regulatory control if phenols, or any other regulated contaminants, are present at levels of regulatory concern. EPA's designation does not change the regulatory management obligations for the recovered material nor does it in any way suggest that the materials are relieved from waste management regulations. The determination as to whether the sands contain contaminants at regulatory levels should be made in accordance with all applicable federal and state regulations and, thus, no additional burden would be placed on any entity to monitor stockpiles as a result of a final designation for this item in the CPG. All actions relating to determining the regulatory status of these sands would be performed by generators or those manufacturing flowable fill, not by those using a commercial product.

Comment: The Illinois Department of Transportation (IDOT) submitted comments in opposition to the use of ferrous foundry sands in flowable fill since, according to IDOT, these sands are normally contaminated with oil. They did not provide any information or data to substantiate this claim. IDOT believes the use of coal fly ash in flowable fill is logical because it has an acceptable track record. IDOT stated that little research has been done on ferrous foundry sand and that its use has been minimal.

EPA contacted the commenter to ascertain the basis for their comment and was told that since the comment was submitted, IDOT has learned that "oil contamination is not always present."

Response: As stated previously, EPA's designation does not change the regulatory management obligations for treatment or management of the recovered material nor does it exempt the materials from existing waste management regulations. The determination as to whether the ferrous foundry sands contain contaminants at regulatory levels should be made in accordance with applicable federal and state regulations before the material is used to make a commercial product.

Comment: American Electric Power (AEP) submitted comments supporting the proposed designation of flowable fill containing ferrous foundry sand and also stated that EPA should note in the CPG and RMAN, that a variety of flowable fills have been successfully developed without the use of cement as an ingredient. AEP referred to flowable fills that use materials such as Class C fly ashes that have a high calcium content, making them appropriate for use in lieu of cement. AEP also stated that these flowable fill mixes, which sometimes utilize other recycled materials such as Class F fly ash and bottom ash as filler, have been approved for use in several states. AEP provided copies of some state specifications.

Response: Information presented in the CPG and RMAN pertains to those items that have been or are being designated by EPA. The designation of items under RCRA section 6002 and E.O. 13101 requires notice and comment before final designations are promulgated. Because EPA did not propose to designate flowable fill containing other materials such as Class C fly ashes, has not reviewed sufficient information on these materials, and did not solicit public comments, no reference or recommendations for these items are appropriate at this time. However, procuring agencies may choose to procure any item containing recovered materials, regardless of whether the item is specifically designated by EPA. Procurement of items containing recovered materials, whether or not they are designated by EPA, is consistent with RCRA section 6002 and E.O. 13101. EPA will consider designating additional flowable fills containing other recovered materials in future amendments to the CPG.

3. Railroad Grade Crossing Surfaces

Comment: The Illinois Department of Transportation (IDOT) submitted comments opposing the designation and recovered materials content recommendations for railroad grade crossing surfaces because crossing designs are usually job-specific, and IDOT believes this designation would inhibit innovation. In addition, IDOT believes it would be very costly to verify the total recovered materials content.

Response: EPA disagrees that designating railroad grade crossing surfaces and providing recommendations on recovered materials content ranges would inhibit innovation. As stated in Table C–11A of RMAN III, "EPA's recommendations do not preclude a procuring agency from purchasing another type of railroad grade crossing surface * * *. They simply require procuring agencies, when purchasing concrete, rubber, or steel grade crossing surfaces, purchase these items made with recovered materials when these items meet applicable specifications and performance requirements." Therefore, job-specific requirements and specifications should be factored into the procuring agency's decision whether to use products containing recovered materials. If railroad grade crossings made with recovered materials do not meet legitimate job-specific requirements, the procuring agency is not required to use the designated items with recovered materials.

EPA disagrees with the commenter's claim that it might be costly to verify recovered materials content in designated items. RCRA section 6002(i) requires that an agency's affirmative procurement program (APP) "contain a program for requiring vendors to estimate, certify, and reasonably verify the recovered materials content of their products." This provision is not meant to burden either of the contracting parties. At the federal level, there are standard provisions for all contracts in the Federal Acquisition Regulations (FAR) that can be used to certify that the products contracted for are delivered. Standard clauses presumably exist for contracts issued by state agencies as well. These standard provisions can be used to certify recovered materials content levels with no extraneous costs to either party.

4. Sorbents

Comment: Synthetic Industries (SI) produces sorbents made of polypropylene (PP) that are used to clean up solvent and oil spills. SI is opposed to the designation of sorbents containing postconsumer recovered PP because, according to SI, such products are technologically infeasible. In addition, SI believes PP sorbents should not be designated for performance-related reasons, citing doubts about the ability of manufacturers to produce a highly sensitive PP product from postconsumer material. SI also stated that it is not feasible to make sorbents with postconsumer PP since it is difficult to obtain a consistent, non-contaminated source of postconsumer PP material. SI stated that if the sorbent's chemical content is not known, it could react with a spilled chemical, create a further hazard, or not work properly.

APPENDIX: B

Quality Assurance(QA)/ Quality Control (QC)

Plan for

Foundry Sand (FS)

Table of Content

QA/QC Plan for Foundry Sand Study

Abstract

During the course of this study, a QA/QC plan was adopted to validate the experimental results. In order to comply with the QA/QC plan, triplicate samples will be prepared for all batch experiments, and the average are reported. Standard testing procedures and analytical methods will be used for quantification. For each sample analysis, an average of two measurements will be made. All analytical methods are subjected to a second source verification by measuring samples of a known quantity in addition to standard calibration.

I. PROGRAM DESCRIPTION

The purpose of this study is to investigate the potential of recycling foundry sand for TxDOT applications. The environmental properties of foundry sand are of interest during this investigation. Thus, the total inorganics, organics and leaching property of foundry sand are evaluated by the EPA SW-846 Method 3050B, 3540 and 1311, respectively. The Method 3050B (Acid Digestion of Sediments, Sludges, and Soils) is a very strong acid digestion method that will dissolve almost all elements that could become "environmentally available (SW 846)." EPA Method 1311 (Toxicity Characteristic Leaching Procedure, TCLP) is designed to determine the mobility of both organic and inorganic present in liquid, solid, and multiphase wastes. Besides these two tests, particle size, pH, moisture content, and loss of ignition of foundry sand are also measured. A quality assurance and quality control (QA/QC) plan is adopted from EPA reports to validate the experimental results during the course of this study. In short, for the QA/QC plan, triplicate samples will be prepared for all batch experiments, and the average are reported. Table 1 summarizes the testing type and the sampling frequency in the testing programs. Table 2 summarizes the total number of analyses, including QC analyses, required for the tests.

Table A1. Summary of critical and non-critical measurements during tests

Measurements	Classification	Measurement Frequency
Total inorganic in foundry sand	Critical	Once the sand is received
Total organic in foundry sand	Critical	Once the sand is received
Leaching property of foundry sand	Critical	Once the sand is received
pH of foundry sand	Non Critical	Once the sand is received
Particle size	Non Critical	Once the sand is received
Moisture content	Non Critical	Once the sand is received
Loss of ignition	Non Critical	Once the sand is received

Table A2. Total number of analyses (including QC) for each foundry sand

Measurement	Total no. of samples
Total inorganic in foundry sand	
Control Blanks	3
Triplicates	3
Independent Check Standard	2
Grand Total	8
Total organic in foundry sand	
Control Blanks	3
Triplicates	3
Independent Check Standard	2
Grand Total	8
TCLP extractable metals in foundry sand	
Control Blanks	3
Triplicates	3
Independent Check Standard	2
Grand Total	8

II. QUALITY ASSURANCE OBJECTIVES

A. DETERMINING QA OBJECTIVES

The goal of this QA/QC plan is to validate the experimental results during the course of this study. To provide reasonable margins of safety, detection limit of 0.5 mg/L for each element are required. These detection limit requirements are greater than at least ten times the instrument detection limit of the ICP, AA, and GC. All other measurements require either a pH meter, a weighing scale, or an oven, and hence method detection limits do not apply.

B. PRECISION, ACCURACY, METHOD DETECTION LIMIT, AND COMPLETENESS

Table 3 summarizes QA objectives for precision, accuracy, and completeness. For all critical measurements, method detection limit is greater than ten times instrument detection limit for all interested parameters measurements.

Precision objectives for all the listed methods except pH are presented as relative percent differences (RPD) of field duplicates. Precision objectives for pH are listed in pH units and expressed as limits for field duplicates.

Table 3. Quality Assurance (QA) objectives for precision and accuracy[1]

Critical Measurement	Matrix	Units	Precision[2] (RPD)	Sample Dilution[3]	Accuracy (%)	Completeness
Total inorganic in sand	Sand	mg/kg	•20%	90-110%	75-125%	90%
Total organic in sand	Sand	mg/kg	•20%	90-110%	75-125%	90%
TCLP extractable metals in foundry sand	Water	mg/L	•20%	90-110%	75-125%	90%
Particle size	Sand	mm	±0.1	—	—	90%
Moisture content	Sand	%	±0.1	—	—	90%
Loss of ignition	Sand	%	±0.1	—	—	90%
pH	Sand	—	±0.1	—	—	90%

1. RPD is the relative percent difference of duplicate sample analyses.
2. Measuring number should be 90-110% of undiluted value.
3. Each sample will be measured twice to get a relative percent difference.

C. COMPARABILITY AND REPRESENTATION

All representative samples will be collected and analyzed in duplicate. Comparability will be ensured by using standard analytical methodologies and reporting units (see Table 4).

D. OTHER QA OBJECTIVES

The material balance will be performed by determining the amount of total contaminant(s) added in spiked samples to the amount of total contaminant(s) in all effluent streams. The mass balance is calculated according to the following expression:

$$PR = \left(\frac{OUT}{IN}\right) \times 100\% \quad , \qquad (1)$$

where PR = percent recovery,

OUT = total contaminants in all output streams, and

IN = total contaminants in all input streams.

For each run to be successful, the mass balance should be between 75 and 125 percent.

E. WHAT IF QA OBJECTIVES ARE NOT MET?

If QA objectives are not met for any run, then that test will be redone. If QA objectives are still not met, the TxDOT project officer will be consulted to determine if (a) the run should again be redone, (b) the statistical confidence level should be reduced, or (c) some of the data should be discarded.

III. SAMPLE LABELING, SAMPLING PROCEDURES, AND CUSTODY

The samples received are stored in a plastic container with a unique label attached to it and kept at room temperature. The label will contain a brief description of the sample, time and date sample was received, and responsible person's name. For testing, several random samples will be collected and mixed in a mixing pan to obtain a homogenized sample. The homogenized sample will be sieved through a sieve no. 50 (size 0.0117-in) and then tested. Tests will be performed within the first 10 days of receiving the samples.

IV. ANALYTICAL PROCEDURES AND CALIBRATION

A. EPA, ASTM and TxDOT TEST METHODS

Table 4 summarizes the standard methods and procedures used in this project.

Table 4. Standard methods and procedures used for extraction and analysis of foundry sand

Parameter	Method	Method Summary	Source
Metal extraction	EPA Method 3050B	Strong acid digestion	EPA, 1994
Hg extraction	EPA Method 7471A	Strong acid digestion	EPA, 1994
SVOC extraction	EPA Method 3540C	SVOC extraction	EPA, 1994
VOC extraction	EPA Method 5021	Petroleum hydrocarbon extraction	EPA, 1994
TPH extraction	TNRCC Method 1005	TPH extraction	TNRCC, 1998
Organic extraction	EPA Method 3550B	Organic extraction	EPA, 1994
Petroleum hydrocarbon	EPA Method 3540	Petroleum hydrocarbon extraction	EPA, 1994
Leaching property	EPA Method 1311	Sodium acetate digestion	EPA, 1994
Hydrocarbon analysis	EPA Method 8100	GC for hydrocarbons analysis	EPA, 1994
Metal analysis	EPA Method 7000	AA for metals analysis	EPA, 1994
Hg analysis	AWWA Method 3500-Hg C	Dithizone method for Hg analysis	EPA, 1994
SVOC analysis	EPA Method 8270	GC for SVOC compounds analysis	EPA, 1994
VOC analysis	EPA Method 8015B	GC for VOC compounds analysis	EPA, 1994
TPH analysis	TNRCC Method 1005	GC for TPH analysis	TNRCC, 1998
pH	EPA Method 3050B	Electrometric method	EPA, 1994
Soil pH	EPA Method 3050B TxDOT Tex-128E	Electrometric method	EPA, 1994 TxDOT, 1999
Particle size	ASTM D422 TxDOT Tex-110E	Sieve analysis	ASTM, 1999 TxDOT, 1999
Moisture content	ASTM D4959 TxDOT Tex-103E	Remove water at 110 ^{o}C	ASTM, 1999 TxDOT, 1999
Loss of ignition	ASTM D2974	Remove organics at 450 ^{o}C	ASTM, 1999

B. NONSTANDARD OR MODIFIED METHODS

No nonstandard methods will be employed.

C. CALIBRATION PROCEDURES AND FREQUENCY

A second source verification will be made for all critical analyses by measuring calibration samples of known concentration prepared from a source separate from the calibration solution. This will be done for all metal analysis and pH measurement. The second source verification will be performed before each new calibration standard is used for analysis. Second source sample concentrations will fall midway between the range of the calibration standards. For all metal analyses, the second source samples must be within 5% of their known value. For the pH measurement, the second source sample must fall within 0.1 pH unit of the known value.

V. DATA REDUCTION, VALIDATION, AND REPORTING

A. DATA REDUCTION

The person performing the study is responsible for data reduction. He/she will be assisted in this effort by the Principal Investigator(s) who will check the raw and reduce data for errors. Equations required to calculate the measured parameters are shown in Table 5.

Table 5. Raw data reduction

Measurement	Raw Data	Equation Used*	Reporting Units
Total inorganic	mg/L solution	Inorganic(s)=RD*DR*SV/SD	mg/kg soil
Total organic	mg/L solution	Organic(s)=RD*DR*SV/SD	mg/kg soil
TCLP extractable inorganic	mg/L solution	TCLP=RD*DR	mg/L solution
pH	—	pH=-Log{H^+}	—
Particle size	—	—	mm
Moisture content	—	% Moisture=(WATER/IN)*100%	%
Loss of ignition	—	% Loss=(OUT/IN)*100%	%

*RD = raw data, DR = dilution ratio, SV = sample volume, SD = weight soil digested

B. DATA VALIDATION

The person performing the study is responsible for data validation. The person performing the study will record all QA data in a chronological log book. Also, the person performing the study will do all calculations and will have to verify the validity of the data by replicating analyses and calculating the QA parameters. When the QA parameters exceed the ranges specified in Table 3, the person performing the study will run the spare samples to replace the data.

C. DATA RECORDING AND REPORTING

The person performing the study is responsible for generating reports of results. Raw data generated for this project will be initially stored as a hard copy in the form of computer printouts and then manually transferred into a chronological log book; other experimental results will be written directly into a chronological lab book. Next, the data will be entered by keyboard into a personal computer spreadsheet program for storage and for calculating precision, accuracy, and completeness of information of analytical results. Computer floppy disk backups of all data will be made weekly and stored outside the laboratory in the Principal Investigator's office. All data generated during this project will be stored for a minimum of 1 year after project completion. All samples will be stored until QA analysis has been performed.

VI. INTERNAL QUALITY CONTROL (QC) CHECKS

A. TYPES OF QC CHECKS

Lab Matrix Spikes

The percentage of recovery of the lab-matrix spike will determine the accuracy of the analysis and will help judge the validity of all samples from that sampling point for that run.

Overall Material Balance

The overall materials balance for each test will be another important process for QC to check. This will be done by determining the amount of inorganic(s) or organic(s) in all input and output streams and the percentage of recovery will be calculated by Eq. [1].

B. ITEMS TO INCLUDE

Table 6 describes the specific QC checks required for each method used in this project. These checks will determine when corrective action is needed on a particular piece of analytical equipment or on a particular method.

Table 6. Scheduled instrument QC checks and calibration

Method	QC Procedure	Frequency	Acceptance Criteria	Corrective Action
ICP (Method 6010)	Calibration curve	every batch	±10% of known sample	Find cause, repair, rerun before sample analysis
	Analyze blank	every batch	±10% of calibration blank sample	Find cause, repair, rerun before sample analysis
	Analyze standard	every batch	±10% of known sample	Find cause, repair, rerun before sample analysis
	Dilute overrange samples	when needed	±10% of original	Find cause, repair, rerun previous samples
	Matrix spike	each batch	80-120% recovery of spike	Find cause, repair, rerun previous samples
GC (Method 6010)	Calibration curve	every batch	±10% of known sample	Find cause, repair, rerun before sample analysis
	Analyze blank	every batch	±10% of calibration blank sample	Find cause, repair, rerun before sample analysis
	Analyze standard	every batch	±10% of known sample	Find cause, repair, rerun before sample analysis
	Dilute overrange samples	when needed	±10% of original	Find cause, repair, rerun previous samples
	Matrix spike	each batch	80-120% recovery of spike	Find cause, repair, rerun previous samples

VII. CALCULATION OF DATA QUALITY INDICATORS

A. COMMON DATA QUALITY INDICATORS

The common indicators will be utilized to determine the quality of the data. These include the following: relative percent difference between triplicate samples (RPD), relative standard deviation (RSD), percent recovery (%R), and percent completeness (%C). The formulas for these indicators are given in Eqs. [2] through [8] which were taken directly from "Preparation Aids for the Development of Category III Quality Assurance Project Plans" (Simes, 1991).

a. Precision

If calculated from duplicate measurements, the relative percent difference is the normal measure of precision:

$$RPD = \frac{(C_1 - C_2)}{(C_1 + C_2)/2} \times 100\% , \qquad (2)$$

where RPD = relative percent difference,

C_1 = larger of the two observed values, and

C_2 = smaller of the two observed values.

If calculated from three or more replicates, use the relative standard deviation:

$$RSD = s/\bar{y} \times 100\% , \qquad (3)$$

where RSD = relative standard deviation,

s = standard deviation, and

$\bar{y}$ = mean of replicate analyses.

Standard deviation is defined as

$$s = \sqrt{\sum_{i=1}^{n} \left(\frac{(y_i - \bar{y})^2}{n - 1}\right)} , \qquad (4)$$

where s = standard deviation,

y_i = measured value of the *i*th replicate,

$\bar{y}$ = mean of replicate measurements, and n = number of replicates.

For measurements, such as pH, where the absolute variation is more appropriate, precision is usually reported as the absolute range, D, of duplicate measurements:

$$D = | m_1 - m_2 | , \qquad (5)$$

where D = absolute range,

m_1 = first measurement, and

m_2 = second measurement.

The standard deviation, s, given above, can also be used.

b. Accuracy

For measurements where matrix spikes are used, calculate the percent recovery as follows:

$$\%R = \left(\frac{S - U}{C_{sa}}\right) \times 100\% , \qquad (6)$$

where %R = percent recovery,

S = measured concentration in spiked aliquot,

U = measured concentration in unspiked aliquot, and

C_{sa} = actual concentration of spike added.

When a standard reference material (SRM) is used, we have

$$\%R = \left(\frac{C_m}{C_{srm}}\right) \times 100\% , \qquad (7)$$

where %R = percent recovery,

C_m = measured concentration of SRM, and

C_{srm} = actual concentration of SRM.

c. Completeness

Completeness is defined as follows for all measurements:

$$\%C = \left(\frac{V}{T}\right) \times 100\% , \tag{8}$$

where

$\%C$ = percent completeness,

V = number of measurements judged valid, and

T = total number of measurements.

B. PROJECT-SPECIFIC INDICATORS

Another important QC check for this project will be to calculate the overall contaminants' mass balance of any test. This will be done by determining the amount of total contaminants in all input and output streams, and percentage of recovery will be calculated by Eq. (1).

VIII. CORRECTIVE ACTION

The corrective actions outlined here will result from the failure to pass the performance evaluation (PE) audits, technical systems audits or the inter-laboratory comparison study. Corrective action will occur when the prime laboratory fails to achieve an average value within 80 to 120% with no single value greater than ±50% of the true value for blind PE samples. If these limits are exceeded, analytical work will stop until the problems are identified and solved. Before work is restarted, another blind performance evaluation sample must be analyzed, and results must meet the acceptance criteria. Results of these PE samples will be included in the final report.

IX. QUALITY CONTROL (QC) REPORTS TO MANAGEMENT

The progress reports from the Principal Investigator will include an updated QA/QC report which covers a detailed discussion of the precision, accuracy, and representatives of the data obtained. As appropriate, these updated reports will contain the performed results and system audits. The final project report or any technical paper for publication in a referred journal will contain a summary of the quality assurance practices and results.

In addition, any problems with quality assurance will be reported verbally to the TxDOT Project Direct (or Committee member) as soon as possible along with recommendations for corrective action. Any changes in QA procedures will be submitted in written form to the TxDOT Director for approval.

X. REFERENCE

1. EPA, 1988b, Preparing Perfect Project Plans - A Pocket Guide for the Preparation of Quality Assurance Project Plans, U.S. EPA Risk Reduction Engineering Laboratory, ORD, Cincinnati, OH, US.
2. Simes, G. F., 1991, Preparation Aids for the Development of Category III Quality Assurance Project Plans, U.S. EPA Risk Reduction Engineering Laboratory, ORD, Cincinnati, OH, US.
3. EPA, 1986, Test Methods for Evaluating Solid Waste
4. TxDOT, 1999, Manual of Testing Procedure

XI. GLOSSARY

Quality Assurance--The total integrated set of activities for ensuring that the uncertainties associated with data derived from environmentally related measurements are known within a stated level of confidence and do not exceed acceptable magnitudes. Quality assurance encompasses the plans, specifications, and policies affecting the collection, processing, and reporting of data. It is the system of activities designed to provide management with independent assurance that total system quality control is being effectively implemented.

Quality Assurance Management Plan--An orderly assemblage of policies, objectives, plans, principles, responsibilities, and procedures by which an organization describes how it intends to produce data of known quality.

Quality Assurance Project Plan--An orderly collection of detailed and specific operational procedures that delineate how a project will be implemented and what quality control procedures will be employed to ensure that data of known quality will be generated; it further specifies how data will be evaluated to assure that it meets specified project goals.

Quality Control--The routine application of prescribed field or laboratory procedures (e.g., periodic calibration, instrument maintenance, animal care and handling, use of blanks, spikes, duplicates) to reduce random and systematic errors and ensure that data are generated within known and acceptable performance limits. Quality control also involves use of qualified personnel, reliable equipment, and supplies; training of personnel; use of good laboratory practices; and strict adherence to standard operating procedures.

APPENDIX: C

Additional Tests on Foundry Sand from Brownwood District for Use in Cemented Sand and Flowable Fill Applications

Submitted to TxDOT Project Committee

August 2000

Additional Environmental Tests on Brownwood Foundry Sand
(Addition to Report submitted in April, 2000)

ABSTRACT

In order to use the stockpile foundry sand (FS) in the Brownwood district for the TxDOT project, the volatile organics (VOC), semi volatile organics (SVOC), total metals, mercury and TPH in the FS were determined using the standard test methods as outlined in the QA/QC Report dated April 2000. SVOC analyses showed that only flouranthene and pyrene were present and the concentrations were below TNRCC RRS2 limits. VOC analysis indicated that all the chemicals analyzed were below the detection limits. Total metal analyses indicated that Al, P and Pb were above the GW-Res limit but only P exceeded the TNRCC GWP-Res limit. No mercury or TPH were detected in the FS.

INTRODUCTION

Additional tests were performed on the Brownwood sand to determine its acceptability. It should be noted that the Brownwood sand has been separately stored and no new FS will be added to the stock pile of FS. All the environmental test results apply to this stock pile of FS from which samples were obtained for analyses.

2. OBJECTIVES

The specific objectives of this study are as follows: (1) to determine the amount of SVOC, VOC, metal, Hg and TPH in the foundry sand, and (2) to compare the concentrations with TNRCC RSS2 risk levels. The Groundwater MSC for Residential Use (GW-Res) and Soil MSC for Residential Use Based on Groundwater Protection (GWP-Res) listed in updated TNRCC Medium-Specific Concentration (MSCs, 1999) were used.

Tests were performed as described in the QA/QC plan.

3. METHODS

Testing methods used in this study are briefly summarized.

3.1 Summary of SVOC Analysis

Extraction: (SW 846 Method 3540C)

1. Determine solid content for foundry sand.
2. Blend 10 g of solid sample with 10 g of anhydrous sodium sulfate.
3. Add 1.0 mL of surrogate standard spiking solution onto the sample.
4. Place 300 mL of extraction solvent and extract 16-24 hours at 4-6 cycles/hour.
5. Solvent: Methylene chloride/Acetone (1:1 v/v).

GC Analysis: (SW 846 Method 8270)

1. Initial column temperature: 40 °C for 4 minutes.
2. Column temperature: 40-270 °C at 10 °C /min;
3. Final temperature: hold at 270 °C until benzoperylene has eluded.
4. Injector temperature: 250-300 °C.
5. Sample volume: 1-2 μL.
6. Carrier gas: hydrogen at 50 cm/sec or helium at 30 cm/sec.

3.2 Summary of VOC Analysis

Extraction: (SW 846 Method 5021)
(Method 5021: Volatile Organic Compounds in Soils and other Solid Matrices Using Equilibrium Headspace Analysis)

1. Determine dry solid content for foundry sand.
2. Place 2 g of soil sample into a screw-top glass headspace vial.
3. Low concentration method: (0.5 to 200 μg/kg)
   a. Add 10-mL matrix modifying solution into the vial. (Matrix modifying solution: add conc. phosphoric acid (H_3PO_4) dropwise to 500 mL of organic free reagent water until pH is 2; add 180 g NaCl; mix well until all components are dissolved.)
   b. Mix the sample for at least 2 min. The vial are heated to 85 °C and allowed to equilibrate for 50 min. Mix the vial for at least 10 min during the equilibrium period.
4. High concentration method: (greater than 200 μg/kg)
   a. Add 10-mL methanol to the vial.
   b. Mix by shaking for 10 min at room temperature.
   c. Withdraw 10 μL, or appropriate volume, and inject into a vial containing 10 mL matrix modifying solution.
   d. Analyze by the above mentioned headspace procedure (3).

GC Analysis: (SW 846 Method 8015B: Nonhalogenated Organics Using GC/FID)

1. Initial temperature: 45 °C for 3 minutes.
2. Program: 45-220 °C at 8 °C /min;
3. Final temperature: 220 °C, hold for 15 min.
4. Injector and detector temperature: 200 °C and 340 °C.
5. Carrier gas: helium at 40 mL/min.
6. Run time: less than 30 min.

3.3 Summary of Metal Analysis

Extraction: (SW 846 Method 3050B)

1. Weight 1.0 g of sample and place in the bottom of digestion vessel.
2. Add 10-mL of 1:1 HNO_3, mix the slurry and heat it to 95 °C for 10 to 15 min.
3. Repeat the process until no brown fumes are observed.
4. Filtered through Whatman No. 41 filter paper before ICP analysis.

3.4 Summary of Hg Analysis

Extraction: (SW 846 Method 7471A)

1. Weight 0.2 g of sample and place in the bottom of BOD bottle.
2. Add 5-mL of reagent water and 5 mL of aqua regia (Aqua regia: HCl/HNO_3 (3:1 v/v).
3. Heat 2 min in a water bath at 95 °C.
4. Cool; then add 50-mL reagent water and 15-mL potassium permanganate solution.
5. Mix thoroughly and place in the water bath for 30 min at 95 °C; cool.
6. A 6-mL of sodium chloride-hydroxyamine sulfate to reduce excess permanganate.

Hg Analysis: (AWWA 3500-Hg C. Dithizone Method)

1. Prepare a calibration curve: add known amount of Hg into separate beakers; add 500-mL water, 1-mL $KMnO_4$ solution, and 10-mL conc. H_2SO_4. Stir and bring to boil. If necessary, add more $KMNO_4$ until a pink color persists.
2. After boiling, add 5-mL $K_2S_2O_8$ solution and cool for 0.5 h.
3. Add one or more drops $NH_2OH.HCl$ solution to discharge the pink color; cool.
4. Add 25-mL dithizone solution; shake separatory funnels and transfer each organic layer to a 250-mL separatory funnel.
5. Repeat the extraction at least 3 times.
6. Add 50-mL 0.25 N H_2SO_4 and 10-mL KBr solution and shake vigorously to transfer Hg-dithizonate from organic layer to aqueous layer.
7. Add 20-mL phosphate-carbonate buffer solution and 10-mL dithizone solution (sample in slightly blue color).
8. Dry contents with anhydrous Na_2SO_4 and record absorbance at 492 nm.
9. Follow the above mentioned procedures for tested sample.

3.5 TPH Analysis

Extraction: (TNRCC Method 1005)

1. Take 10 g of samples in 40-mL vial.
2. Add 2 mL of methanol, cap and vortex for 20 sec to remove water from sample.
3. Add 10 mL of n-pentane (reagent grade), cap and proceed with the extraction.
4. Collect sample and centrifuge at 15-G for 20 minutes.
5. Collect supernatant for GC analysis.
6. Use Ottawa sand as control sample.

GC Analysis:

1. Initial temperature: 30 °C for 3 minutes.
2. Ramp at 15 °C /min to 300 °C, hold for 5 minutes.
3. Ramp at 15 °C /min to 325 °C and hold for the remainder of the 30 minutes
4. FID temperature: 325 °C.
5. Injector temperature: 285 °C.

4. RESULTS

3.1 SVOC

Among the 16 SVOCs analysis, only fluoranthene and pyrene were detected in foundry sand samples. Both concentrations were below TNRCC GW-Res and GWP-Res standards. The rest of SVOCs were below the detection limit for each chemical.

3.2 VOC

All 19 VOCs chemicals analyzed were below the detection limit for each chemical. Thus, none was violated TNRCC GW-Res and GWP-Res standards.

3.3 Total Metal Analysis

Among the 27 metals analysis, only Al, P, and Pb over the TNRCC GW-Res standard. However, only P violated TNRCC GWP-Res standard. Among the ions, B, Ca, Fe, K, Li, Mg, Na, S, Si, Sr, and Ti are not regulated by TNRCC.

3.4 Mercury Analysis

Hg was not detected in the foundry sand samples. Thus, it did not violate TNRCC GW-Res and GWP-Res standard.

3.5 TPH Analysis

None of TPH compound (C_6 - C_{28} hydrocarbon) was detected in the foundry sand. Thus, TNRCC GW-Res and GWP-Res standards were not violated.

5. CONCLUSIONS

Based on the experimental results and analyses of the test data on the foundry sand obtained from Brownwood district following conclusions are advanced:

1. **VOC**: Only fluoranthene and pyrene were detected in foundry sand samples. Both concentrations were below TNRCC GW-Res and GWP-Res standards.
2. **SVOC**: None were detected.
3. **Metals**: Only Al, P, and Pb were over the TNRCC GW-Res standard. However, only P violated TNRCC GWP-Res standard.
4. **Mercury**: Not detected.
5. **TPH**: None were detected.

6. REFERENCES

[1] AWWA, 1992, Standard Methods for the Examination of Water and Wastewater

[2] EPA, 1986, Test Methods for Evaluating Solid Waste: Physical/Chemical Method

[2] TNRCC, 1998, TNRCC Method 1005 - Total Petroleum Hydrocarbons

[3] TNRCC, 1999, TNRCC Undated Examples of Standard No. 2, Appendix II Medium-Specific Concentration (MSCs)

Table C1. Summary of SVOC analysis and Comparison with TNRCC GW-Resident standard

	GW-Res	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	**Exceed Limit**		FS9-2-A	FS9-2-B	FS9-2-C	Avg	**Exceed Limit**	
Element	**mg/L**	mg/L	mg/L	mg/L	mg/L	mg/L	**Yes**	**No**	mg/L	mg/L	mg/L	mg/L	**Yes**	**No**
Acenaphthene	**2.2**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Acenaphthylene	**2.2**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Anthracene	**11**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(a)anthracene	**0.0002**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(b)fluoranthene	**0.0002**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(k)fluoranthene	**0.0012**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(g,h,I)perylene	**1.1**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(a)pyrene	**0.0002**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Chrysene	**0.012**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Dibenzo(a,h)anthracene	**0.0002**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Fluoranthene	**1.5**	0.01	0.943	0.928	0.934	0.935		x	ND	ND	ND	ND		x
Fluorene	**1.5**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Indeno(1,2,3-cd)pyrene	**0.0002**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Naphthalene	**0.73**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Phenanthrene	**2**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Pyrene	**1.1**	0.01	0.464	0.425	0.448	0.446		x	0.156	0.155	0.152	0.154		x

*. TNRCC Medium Specific Concentration (1999)
**. ND: Not detected

Table C2. Summary of SVOC analysis and Comparison with TNRCC GWP-Resident standard

	GWP-Res	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	**Exceed Limit**		FS9-2-A	FS9-2-B	FS9-2-C	Avg	**Exceed Limit**	
Element	**mg/kg**	mg/kg	mg/kg	mg/kg	mg/kg	mg/L	**Yes**	**No**	mg/kg	mg/kg	mg/kg	mg/kg	**Yes**	**No**
Acenaphthene	**220**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Acenaphthylene	**220**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Anthracene	**1100**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(a)anthracene	**0.02**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(b)fluoranthene	**0.02**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(k)fluoranthene	**0.12**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(g,h,I)perylene	**110**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Benzo(a)pyrene	**0.02**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Chrysene	**1.2**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Dibenzo(a,h)anthracene	**0.02**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Fluoranthene	**150**	0.01	37.708	37.120	37.360	24.946		x	ND	ND	ND	ND		x
Fluorene	**400**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Indeno(1,2,3-cd)pyrene	**0.02**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Naphthalene	**7.3**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Phenanthrene	**110**	0.01	ND	ND	ND	ND		x	ND	ND	ND	ND		x
Pyrene	**110**	0.01	18.544	17.000	17.920	11.851		x	6.236	6.200	6.080	4.145		x

*. TNRCC Medium Specific Concentration (1999)
**. ND: Not detected

Table C3. Summary of VOC analysis and Comparison with TNRCC GW-Resident standard

	GW-Res*	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	Exceed Limit		FS9-2-A	FS9-2-B	FS9-2-C	Avg	Exceed Limit	
Element	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**Yes**	**No**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**Yes**	**No**
Benzene	**0.005**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Carbon tetrachloride	**0.005**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Chlorobenzene	**0.1**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Chloroform	**0.1**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Dibromochloromethane	**0.1**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Dichlorodifluoromethane	**7.3**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1-Dichloroethane	**3.7**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,2-Dichloroethane	**0.005**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Ethylbenzene	**0.7**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Methylene chloride	**0.005**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Naphthalene	**0.73**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Styrene	**0.1**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1,1,2-Tetrachloethane	**0.033**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1,2,2-Tetrachloethane	**0.0043**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Toluene	**1**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Vinyl chloride	**0.002**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
m-Xylene	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
o-Xylene	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
p-Xylene	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x

*. TNRCC Medium Specific Concentration (1999)
**. ND: Not detected

Table C4. Summary of VOC analysis and Comparison with TNRCC GWP-Resident standard

	GWP-Res	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	Exceed Limit		FS9-2-A	FS9-2-B	FS9-2-C	Avg	Exceed Limit	
Element	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	Yes	No	mg/kg	mg/kg	mg/kg	mg/kg	Yes	No
Benzene	**0.5**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Carbon tetrachloride	**0.5**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Chlorobenzene	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Chloroform	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Dibromochloromethane	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Dichlorodifluoromethane	**730**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1-Dichloroethane	**370**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,2-Dichloroethane	**0.5**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Ethylbenzene	**70**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Methylene chloride	**0.5**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Naphthalene	**73**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Styrene	**10**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1,1,2-Tetrachloethane	**3.3**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
1,1,2,2-Tetrachloethane	**0.43**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Toluene	**100**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
Vinyl chloride	**0.2**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
m-Xylene	**1000**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
o-Xylene	**1000**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x
p-Xylene	**1000**	0.01	ND	ND	ND	0.000		x	ND	ND	ND	0.000		x

*. TNRCC Medium Specific Concentration (1999)
**. ND: Not detected

Table C5. Summary of Metal analysis and Comparison with TNRCC GW-Resident standard

	GW-Res	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	**Exceed Limit**			FS9-2-A	FS9-2-B	FS9-2-C	Avg	**Exceed Limit**		
Element	**mg/L**	mg/L	mg/L	mg/L	mg/L	mg/L	**Yes**	**No**	**NA**	mg/L	mg/L	mg/L	mg/L	**Yes**	**No**	**NA**
Ag	**0.18**	0.005	0.004	0.005	0.005	0.005		x		0.005	0.005	0.005	0.005		x	
Al	**3.7**	0.02	74.049	65.519	66.608	68.725	x			2.7021	2.491	2.597	2.597		x	
As	**0.05**	0.02	0.037	0.021	0.020	0.026		x		0.02	0.02	0.020	0.020		x	
B		0.01	0.247	0.358	0.440	0.348			x	14.0651	13.8921	13.979	13.979			x
Ba	**2**	0.005	0.378	0.312	0.392	0.361		x		0.3879	0.4846	0.436	0.436		x	
Be	**0.004**	0.0002	0.003	0.002	0.002	0.002		x		0.0021	0.0023	0.002	0.002		x	
Ca		0.02	45.104	41.609	44.979	43.897			x	34.5003	35.1167	34.809	34.809			x
Cd	**0.005**	0.001	0.003	0.001	0.001	0.002		x		0.003	0.0036	0.003	0.003		x	
Co	**2.2**	0.005	0.005	0.003	0.002	0.003		x		0.005	0.005	0.005	0.005		x	
Cr	**0.1**	0.005	0.035	0.026	0.034	0.032		x		0.005	0.005	0.005	0.005		x	
Cu	**1.3**	0.005	0.084	0.059	0.056	0.066		x		0.0073	0.005	0.006	0.006		x	
Fe		0.02	43.267	36.728	37.075	39.023			x	0.02	0.02	0.020	0.020			x
K		0.1	6.281	5.660	2.914	4.952			x	0.1	0.1	0.100	0.100			x
Li		0.5	0.030	0.027	0.024	0.027			x	0.5	0.5	0.500	0.500			x
Mg		0.2	42.354	36.275	34.870	37.833			x	47.842	47.1707	47.506	47.506			x
Mn	**1.7**	0.005	0.569	0.441	0.442	0.484		x		0.2914	0.2995	0.295	0.295		x	
Mo	**0.18**	0.01	0.006	0.006	0.004	0.005		x		0.01	0.01	0.010	0.010		x	
Na		2	48.692	45.001	23.622	39.105			x	2260.52	2215.27	2237.89	2237.89			x
Ni	**0.73**	0.002	0.029	0.024	0.026	0.026		x		0.011	0.0035	0.007	0.007		x	
P	**0.00073**	0.05	0.542	0.422	0.446	0.470	x			0.1988	0.2246	0.212	0.212	x		
Pb	**0.015**	0.01	0.107	0.076	0.085	0.089	x			0.0277	0.0345	0.031	0.031	x		
S		0.1	22.717	20.849	9.395	17.654			x	12.5533	12.4573	12.505	12.505			x
Si		0.02	2.315	2.288	0.547	1.717			x	105.066	115.719	110.392	110.392			x
Sr		0.01	0.677	0.591	0.449	0.572			x	1.0372	1.0397	1.038	1.038			x
Ti		0.01	0.082	0.085	0.075	0.081			x	0.01	0.01	0.010	0.010			x
V	**0.26**	0.005	0.015	0.010	0.008	0.011		x		0.005	0.005	0.005	0.005		x	
Zn	**1.1**	0.005	0.324	0.272	0.376	0.324		x		0.0968	0.0868	0.092	0.092		x	
Hg	**0.002**	0.0001	ND	ND	ND	ND		x		ND	ND	ND	ND		x	

*. TNRCC Medium Specific Concentration (1999)
**. NA: Not applicable
ND: Not detected

Table C6. Summary of Metal analysis and Comparison with TNRCC GWP-Resident standard

	GW-Res	Detection limit	FS9-1-A	FS9-1-B	FS9-1-C	Avg	**Exceed Limit**			FS9-2-A	FS9-2-B	FS9-2-C	Avg	**Exceed Limit**		
Element	**mg/kg**	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	**Yes**	**No**	**NA**	mg/kg	mg/kg	mg/kg	mg/kg	**Yes**	**No**	**NA**
Ag	**1.8**	0.005	0.040	0.050	0.050	0.047		x		0.1	0.1	0.100	0.050		x	
Al	**3700**	0.02	740.490	655.190	666.080	687.253		x		54.042	49.82	51.931	25.966		x	
As	**5**	0.02	0.370	0.210	0.200	0.260		x		0.4	0.4	0.400	0.200		x	
B		0.01	2.470	3.580	4.400	3.483			x	281.302	277.842	279.572	139.786			x
Ba	**200**	0.005	3.780	3.120	3.920	3.607		x		7.758	9.692	8.725	4.363		x	
Be	**0.4**	0.0002	0.030	0.020	0.020	0.023		x		0.042	0.046	0.044	0.022		x	
Ca		0.02	451.040	416.090	449.790	438.973			x	690.006	702.334	696.170	348.085			x
Cd	**0.5**	0.001	0.030	0.010	0.010	0.017		x		0.06	0.072	0.066	0.033		x	
Co	**220**	0.005	0.050	0.030	0.020	0.033		x		0.1	0.1	0.100	0.050		x	
Cr	**10**	0.005	0.350	0.260	0.340	0.317		x		0.1	0.1	0.100	0.050		x	
Cu	**130**	0.005	0.840	0.590	0.560	0.663		x		0.146	0.1	0.123	0.062		x	
Fe		0.02	432.670	367.280	370.750	390.233			x	0.4	0.4	0.400	0.200			x
K		0.1	62.810	56.600	29.140	49.517			x	2	2	2.000	1.000			x
Li		0.5	0.300	0.270	0.240	0.270			x	10	10	10.000	5.000			x
Mg		0.2	423.540	362.750	348.700	378.330			x	956.84	943.414	950.127	475.064			x
Mn	**170**	0.005	5.690	4.410	4.420	4.840		x		5.828	5.99	5.909	2.955		x	
Mo	**18**	0.01	0.060	0.060	0.040	0.053		x		0.2	0.2	0.200	0.100		x	
Na		2	486.920	450.010	236.220	391.050			x	45210.4	44305.3	#######	22378.93			x
Ni	**73**	0.002	0.290	0.240	0.260	0.263		x		0.22	0.07	0.145	0.073		x	
P	**0.073**	0.05	5.420	4.220	4.460	4.700	x			3.976	4.492	4.234	2.117	x		
Pb	**1.5**	0.01	1.070	0.760	0.850	0.893		x		0.554	0.69	0.622	0.311		x	
S		0.1	227.170	208.490	93.950	176.537			x	251.066	249.146	250.106	125.053			x
Si		0.02	23.150	22.880	5.470	17.167			x	2101.32	2314.38	#######	1103.925			x
Sr		0.01	6.770	5.910	4.490	5.723			x	20.744	20.794	20.769	10.385			x
Ti		0.01	0.820	0.850	0.750	0.807			x	0.2	0.2	0.200	0.100			x
V	**26**	0.005	0.150	0.100	0.080	0.110		x		0.1	0.1	0.100	0.050		x	
Zn	**1100**	0.005	3.240	2.720	3.760	3.240		x		1.936	1.736	1.836	0.918		x	
Hg	**0.2**	0.001	ND	ND	ND	ND		x		ND	ND	ND	ND		x	

*. TNRCC Medium Specific Concentration (1999)

**. NA: Not applicable

ND: Not detected