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Stabilization of Marginal Soils Using Recycled Materials

by

Delfin G. Carreon Jr.

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Major Professor: Alaa K. Ashmawy, Ph.D.
Manjriker Gunaratne, Ph.D.
Abla Zayed, Ph.D.

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Keywords: waste materials, municipal solid waste, industrial by-products, geotechnical, beneficial reuse

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Dedication

This work is dedicated to my parents. They've supported me mentally, physically, and most of all, financially in my efforts to achieve a master's degree in geotechnical engineering at the University of South Florida.

Acknowledgement

There are several people to thank for their efforts and help in this research. First and foremost would have to Dr. Ashmawy. Even though he wasn't always around, I would not have been able to complete this work without his guidance and direction. My colleagues at the University of South Florida including Brian Runkles, Nivedia Das, Aidee Cira, and the boss himself Mr. Maged Mishriki offered their insight and time in helping with this project. And of course, my friends who were there for me when I needed them most.

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Stabilization of Marginal Soils Using Recycled Materials

Delfin G. Carreon Jr.

ABSTRACT

Marginal soils, including loose sands, soft clays, and organics are not adequate materials for construction projects. These marginal soils do not possess valuable physical properties for construction applications. The current methods for remediation of these weak soils such as stone columns, vibro-compaction, etc. are typically expensive. Waste materials such as scrap tires, ash, and wastewater sludge, offer a cheaper method for stabilizing marginal soils. As an added benefit, utilizing waste materials in soil stabilization applications keeps these materials from being dumped into landfills, thereby saving already depleting landfill space. Included in this report is an extensive investigation into the current state of research on waste and recycled materials in construction applications. Also included is an investigation on actual implementation of this research in construction projects. Upon completion of this investigation, an effort was made to determine waste materials specific to the state of Florida (waste roofing shingles, municipal solid waste ash, waste tires, and paper mill sludge) that could be used in stabilizing marginal soils through soil mixing techniques. Changes in the engineering properties of soils as a result of adding these waste materials were studied and recommendations on implementing these effects into construction applications are offered.

Chapter 1: Introduction

Introduction

Recycled materials such as paper mill sludge and scrap roof shingles show potential for use in geotechnical engineering applications. These materials can be processed to a more desirable product or used in their natural state as a suitable construction material. Part of the driving force for pushing recycled materials research is the fact that these materials possess equivalent or even better engineering properties typical for the conventional construction materials. The other part would be the fact that reusing these materials ultimately keeps them out of landfills. This is paramount due to the fact that landfill space is constantly and rapidly depleting.

Scope of Project

There are three major tasks associated with the current research. The first task was a comprehensive literature review and information collection on recycled materials. In the past, much effort has been made to find new applications for recycled materials. Depleting landfill space is the major motivation for such research. Finding new uses for materials that typically end up in landfills is mandatory in order to keep from using land for landfills. This first task was time-consuming mostly because of the vast amounts of information available from so many different sources. As a result of this literature review and information collection, specific materials were chosen to be part of the next task, the experimental program.

The experimental program included testing materials chosen for the current research. Tests were conducted to determine index properties, compaction properties, and strength properties of the materials. The materials were then blended with either sand or clay and tested further in order to determine how these materials affected the properties of the sand and clay.

The third task included updating of the recycled materials relational database. Past research on recycled materials led to the creation of a database including all important information when considering the use of recycle materials in various applications. The database was populated with information collected from the literature review as well as results from the experimental program of the current research.

Organization of Thesis

Chapter 2 will contain introduce the list of materials considered in this study. A breakdown of the materials is included as well a literature review on the materials selected for the testing program of this study. Chapter 3 includes a detailed description and characterization of the materials tested including index properties and environmental issues. Chapters 4 and 5 discuss the compaction behavior and shear strength properties of the materials, respectively. Chapter 6 includes a brief discussion of the recycled materials database that was updated as a result of the literature review. Chapter 7 includes conclusions and recommendations as a result of this study.

Chapter 2: Literature Review

Introduction

The idea of using recycled materials in construction applications is not a new concept. Reports on this subject can be found dating back to the 1970's. The Organization for Economic Co-operation and Development (OECD) published a report in 1977 entitled, "Use of Waste Materials and By-products in Road Construction." The OECD was a conglomeration of countries including the United States that was put together in 1960. Their report contained information on domestic and industrial wastes and how each could be utilized in roadway construction.

Using recycled materials in construction makes sense because they offer two major advantages over traditional construction materials. First, they are typically less costly due to the fact that they are a waste product that already needs to be disposed of. Second, finding alternative uses for these materials keeps them out of landfills, ultimately saving already depleting landfill space. These two points alone make the case for finding alternative reuse applications for recycled materials.

Breakdown of Materials

At the beginning of literature for the current research, an initial list of 24 waste and recycled materials was compiled. These 24 initial materials were chosen for their potential to serve as a construction material in civil engineering applications, with a focus on the geotechnical side. In other words, these materials were chosen for their potential to serve as either fill material, base or subbase material for roadway construction, or as a soil amendment for stabilizing weak soils. Another reason for these materials to be chosen was that each one on the initial list of 24 were reported to have been either studied for alternative reuse applications, actually implemented in a reuse application or both.

This list included materials ranging from municipal wastes such as paper, glass, and plastics to industrial wastes like slag and coal combustion by-products. A complete list of these materials is shown in Table 2-1.

Table 2-1: Initial List of 24 Materials

Paper	Demolition Debris	Paper Mill Sludge
Plastics	Blast-Furnace Slag	Wood Waste
Incinerator Ash (MSW)	Steel Mill Slag	Carpet Fibers
Scrap Tires	Non-Ferrous Slag	Mine Tailings
Roof Shingles	Cement/Lime Kiln Dust	Phosphogypsum
Fly Ash (Coal Ash)	Reclaimed Asphalt Pavement	Quarry Waste
Bottom Ash (Coal)	Reclaimed Concrete Pavement	Glass
Scrubber Base (Coal)	Foundry Wastes	Boiler Slag

During the literature review it was determined that only certain materials would be taken into consideration during the testing program. Certain criteria were set for each material to meet in order to decide whether or not the material would be tested. Two major aspects of each material were evaluated: availability in Florida and environmental issues. The availability of the material is important because if sufficient amounts are not being produced, then it would not be a wise choice of construction material. Environmental issues were a major criterion because some of the materials such as phosphogypsum are associated with radon emissions and would not be considered in the testing program. A flowchart was developed, shown in Figure 2-1 and each material was subjected to it.

Once each material was subjected to the flowchart, 4 materials were selected to be considered in the testing program. These materials showed that ample amounts were produced and that they were more or less safe enough to be considered for reuse in geotechnical applications. The materials selected for the current research included: municipal (MSW) solid waste incinerator ash, scrap roof shingles, paper mill sludge, and scrap tires. The rest of this chapter will discuss the past research conducted specific to these 4 materials.

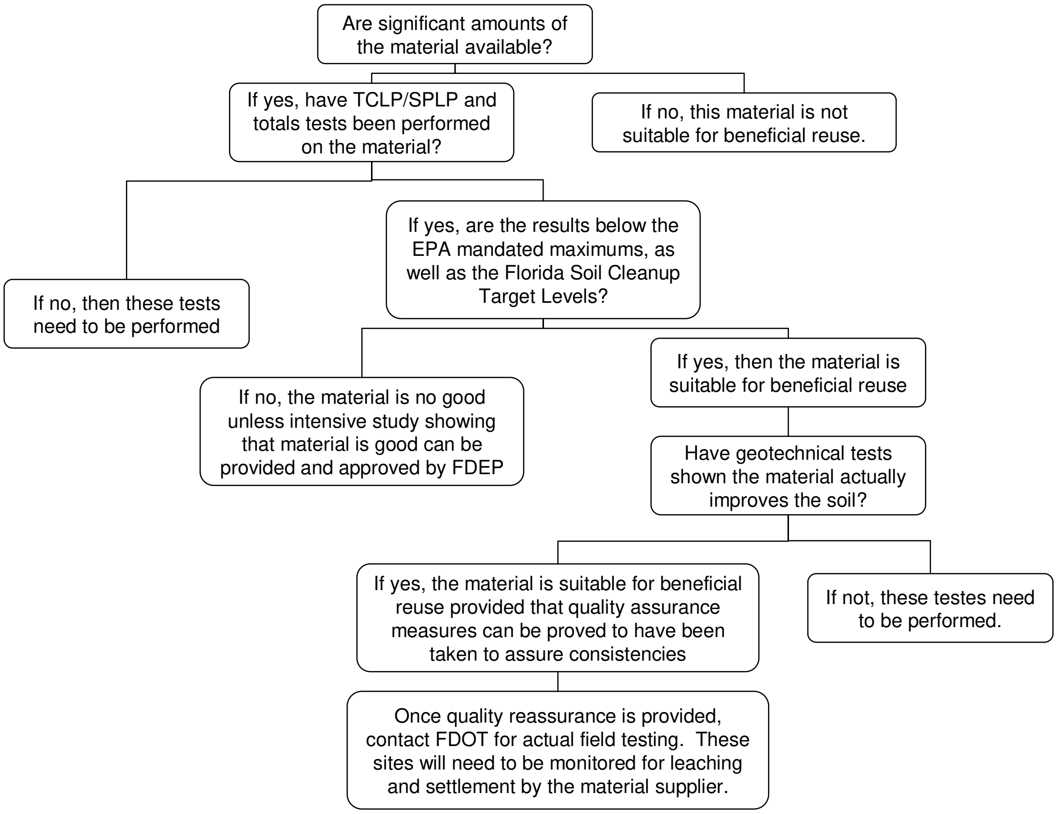


Figure 2-1: Materials Flowchart

MSW Ash

A fair amount of research has been conducted on the properties and potential reuse application of MSW ash. A 2004 study by Muhunthan et al. investigated the geotechnical properties of MSW ash mixes. The mixes in this study included blends of bottom ash and fly ash produced at a mass burn facility in Spokane, Washington. The blends tested were composed of 0, 20, 40, 60, 80, and 100% bottom ash to fly ash and visa versa totaling 6 different blends. Samples were tested for compaction behavior, shear strength by the direct shear test, and permeability.

From the compaction tests, it was seen that the incinerator ash mixes exhibit behavior similar to that of clays. It should also be noted that incinerator ash mixes achieved much lower unit weights than typical values for sand and clay (Muhunthan et al., 2004). When comparing bottom ash to fly ash it was seen that the 100% bottom ash sample exhibited significantly lower optimum moisture content than the 100% fly ash sample. This was explained by the fact that fly ash contained much more smaller particles than bottom ash thereby increasing the amount of surface area of particles to be covered with moisture. (Muhunthan et al., 2004).

Direct shear tests were conducted on each blend at optimum moisture content and on the as-received samples of incinerator ash. Results showed that the friction angle for the blends increased with percentage of bottom ash with the highest value being 50.7^0 for the 100% bottom ash blend. The opposite was true for calculated cohesion values. The cohesion of the blends decreased with increasing percentage of fly ash with the highest value being 34.1 kPa for the 100% fly ash blend.

The overall results from the direct shear testing showed that incinerator ash blends will tend to have better strength characteristics than typical fill materials and since ash is relatively lighter than typical fill material, lower normal stresses. This in turn will allow for the generation of lower normal stresses on foundation soils (Muhunthan et al., 2004). Similar to the direct shear tests, permeability was investigated on all blends at optimum moisture content as well as at as-received moisture content. Results indicated that 100% bottom ash gave a permeability coefficient of 1.4×10^{-3} cm/sec at optimum moisture content. This study did not include any data on the chemical composition of the MSW ash tested or how applying this material in construction applications would affect the surrounding environment.

A similar study on the use of MSW ash as a highway fill material was conducted in 1995 by Consentino et al. The major difference when compared to Muhunthan et al, 2004 is that this study included an in depth investigation into the environmental impacts of reusing MSW ash. In this study an actual embankment made from combined bottom and fly MSW ash was designed and constructed. The field performance of the embankment was evaluated as well as its environmental characteristics. A leachate collection system was installed during construction of the embankment. Rainwater runoff was also collected. The leachate and runoff collected was analyzed for heavy metal concentrations and toxicity limits.

The results of this study indicated that toxicity limits were not exceeded in the runoff or the leachate after 6 months. Drinking water standards were also taken into consideration. These standards were slightly exceeded in the leachate which showed a selenium concentration of 0.13 mg/l. The drinking water standard for selenium concentration is 0.1 mg/l.

Overall the results from this study and the study by Muhunthan et al, 2004 indicate that MSW incinerator ash would make a proficient construction material when blends of bottom ash and fly ash are used. It is now pertinent to investigate how adding MSW ash would affect the engineering properties of sand or clay as in the current research.

Scrap Roof Shingles

There has not been as much research on the beneficial reuse of scrap roof shingles when compared to other widely researched recycled materials such as scrap tires or MSW ash. Reported reuses of scrap roof shingles include using the material as an additive to hot mix asphalt and as a gravel substitute for the wearing surface of rural roads.

In a 2004 study by Hooper and Marr, the effects of adding asphalt shingle tabs to different soils including crushed stone gravel, a silty sand, a clean sand, and clay was investigated. When mixing the shingle material with crushed stone gravel 5 different mix percentages were tested. Varying amounts of shingle tabs of 25.4 mm minus (0, 33, 50, 67, and 100% by volume) were added to the gravel. For the clean sand, silty sand, and clay a fixed amount of 33% by volume shingle tabs were blended in.

A number of different tests were conducted on these samples, including sieve analysis, Atterberg limits, compaction, and California bearing ratio (CBR). Test results from this study varied with shingle to soil mix percentages. Adding the shingle tabs to crushed stone gravel, silty sand, and clean sand resulted in a decreasing affect on the strength according to the CBR test. The only strength increase was experienced when the shingles were added to clay. This can be explained by the ability of the clay to hold the shingle tabs in place by cohesion. This would allow for the shingles to remain in place during loading and refrain from slipping. This in turn would for the distribution of pressures throughout the sample as the load is applied (Hooper and Marr, 2004).

The study by Hooper and Marr, 2004 does give an idea on how addition of scrap shingle tabs can affect the strength of different types of soils however; the shingles used in this study were obtained from a pre-consumer source. They were basically the scraps leftover from shingle production. This source of waste shingles will typically end up in a landfill and is in need of some sort of recycling application but only makes up 10% of the total shingle waste produced nationally. The majority of shingle waste produced comes from tear-off post consumer shingles. For the current research, post-consumer tear-off shingles will be evaluated when mixed with soils. The other issue related to scrap shingle reuse not mentioned in this study is the potential for the material to contain asbestos. This is an issue that needs to be addressed when one is considering reusing scrap roof shingles.

Paper Mill Sludge

Paper mill sludge is a by-product of the paper manufacturing industry. There have been several studies on reuse applications for paper mill sludge. A study completed by Moo-Young and Zimmie 1996 was conducted in order to determine the geotechnical properties of paper mill sludges specifically for use in landfill covers. They collected and studied 7 different paper mill sludges from different sources including wastewater treatment plants, paper mills, and a sludge monofill. The sludges were tested for geotechnical properties such as Atterberg limits, compaction behavior, shear strength and permeability.

All of the sludges studied exhibited high water content, high compressibility, and low solid content. The fact that the sludge can be compacted to low permeability makes this material ideal for use as hydraulic barrier for landfills (Moo-Young and Zimmie, 1996). Problems occurred during testing since the sludge has a tendency to form coarse flocs upon drying, which are difficult to pulverize. All the sludge samples collected exhibited high Atterberg limits. There was a wide range of optimum moisture contents from 50 to 100%. Shear strength testing was completed using consolidated undrained triaxial compression tests with pore pressure measurements. Friction angles ranged from 25^0 to 40^0 while the cohesion was between 2.8 and 9 kPa. Results from this study indicate that paper mill sludge would make a suitable landfill cover material.

Another study conducted by Simpson et al. 2004 looked at the overall history and technology associated with the beneficial reuse of paper mill sludge. Overall, the major reuse application for paper mill sludge has been using the material for landfill cover. According to this study paper mill sludge, termed fiber-clay when talking about reuse, has been combined with pozzolanic material (fly ash) and used as both subbase material and as a finished surface for secondary and remote access roads.

Simpson et al also describes the thixotropic properties of paper mill sludge. In other words, when the sludge is dried to around the optimum moisture content (typically around 60%) the material resembles paper mache. Addition of moisture however, does not return the material to its original consistency, but rather to a mixture of lumps of paper mache in water (Simpson et al., 2004). Other reported reuses for paper mill sludge according to this study include kitty litter, worm bedding, commercial absorbents, and agricultural animal bedding. Neither of the two studies mentioned on paper mill sludge addressed the environmental hazards associated with reusing paper mill sludge, such as potential for leaching of heavy metals.

Scrap Tires

Similar to MSW ash, scrap tires have been studied extensively with regards to alternative forms of disposal and recycling. Tires have been reused in many different applications mainly related to production of new rubber based materials. Another major form of tire recycling is burning tires for fuel at tire derived fuel (TDF) facilities. There have also been reports that describe construction related applications for waste tires such as crumb rubber modifiers for highway pavement and shredded tires as fill material. The reuse application for tires is dependent on how the tires are processed. Processing basically includes shredding, removing of metal reinforcing, and further shredding until the desired material is achieved.

In a report by Edinciler et al, 2004 the researches looked at the effects on the shear strength of sand when tire buffings are added. Tire buffings, shown in Figure 2-2, are the by-product of the tire retread process. The tire buffings in this study were between 1 and 4 mm in diameter and 2 to 40 mm in length. The small diameter and fiber shape of the buffings make them ideal form mixing with soil compared to tire shreds or chips (Edinciler et al., 2004).

Figure 2-2: Tire Buffings

Large scale direct shear tests were conducted on the buffings themselves and on a sand-tire buffing blend. Results show that at low a vertical stress of 20 kPa, the addition of tire buffings stiffened the sand at low deformations. At higher vertical stresses the (40 kPa) the addition of tire buffings lowers the ultimate strength of sand, however the displacement at failure shifts from 12 mm for sand only to 35 mm when buffings are added. From these results, it can be deduced that adding tire buffings to an embankment material can allow for the embankment to undergo larger strains without failure.

A report by Consentino et al., 1995 investigated the basic engineering properties and environmental impacts of using waste tire chips in highway construction applications. The report suggested utilizing scrap tire chips as a lightweight fill material. Scrap tire chips would make an ideal lightweight fill because they’re readily available, relatively inexpensive (by-product), and are easily handled by standard construction equipment. A couple of downfalls associated with using scrap tire chips as lightweight fill include the fact that design parameters are based on field trials and the restricted use below the groundwater table (Consentino et al, 1995).

The report by Consentino et al, 1995 also included information on the environmental impacts of using scrap tire chips as fill material. TCLP testing and extraction procedure (EP) toxicity tests were conducted on scrap tire chip samples. TCLP results indicated that the leachate from the samples were one to three times less than TCLP regulatory levels. The EP toxicity test showed that the amount of heavy metals extracted from the samples were well below EPA toxicity levels. Another major risk associated with reusing scrap tires discussed in the report by Consentino et al, 1995 was the potential for spontaneous combustion. Reports of fires occurring at tire stock piles have been noted and investigated. Studies have shown that the primary reason for combustion occurring is heat accumulation by exothermic reactions due to oxidation of exposed steel in the tires. This can be avoided when using scrap tires as fill material by removing the steel during the shredding process (Consentino et al., 1995).

Chapter Three: Materials

Introduction

For the current research, four materials were considered for beneficial reuse in soil stabilization applications. These materials included: municipal solid waste (MSW) incinerator ash, scrap roofing shingles, crumb rubber tires, and paper mill sludge. These materials were selected based on their engineering properties, availability in Florida, and their potential for use in geotechnical applications.

For the current research the main application of these materials focused on soil blending. In other words, these materials were mixed with soils and tested in order to determine whether or not the addition of the material enhanced the engineering properties of the soil itself. Each material was mixed with either sand or organic material and tested for index properties, compaction behavior, and strength effects. This chapter contains information pertaining to the origin, description, and index properties of each material, as well as some current reuse applications. Also included in this chapter is information related to the environmental impacts of applying these materials in soil blending applications.

Material Descriptions

MSW Ash

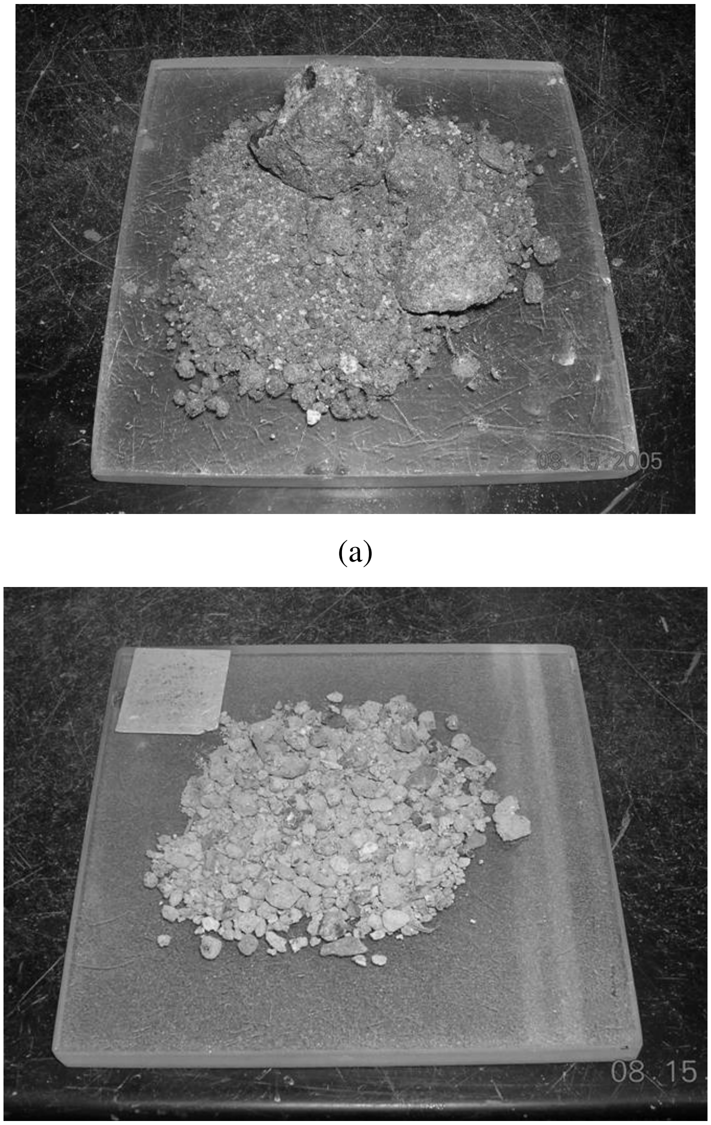
MSW ash is a by-product that is produced as a result of burning municipal solid waste. There are two different types of facilities that produce MSW ash, mass burn and refuse derived fuel (RDF). Mass burn facilities basically incinerate all the waste entering in the waste stream. RDF facilities process the incoming waste by removing the inorganic content such as glass, ceramics, and metals prior to incineration. Although RDF facilities make an effort to separate the waste before it is incinerated there is still a large variability in the composition of the resulting ash. This has led to some hesitation in considering MSW ash for use in construction applications. MSW ash has been used in asphalt concrete applications and in asphalt paving mixes, however the material has been termed “borderline” hazardous by the EPA due to its potential for leaching of hazardous materials. Previous research on MSW ash in reuse applications has resulted in reported engineering properties summarized in Table 3-1.

Table 3-1: Engineering Properties for MSW Ash

Unit Weight (kg/m^3)	965 - 1290
Specific Gravity	1.86 - 2.24
CBR Value	95 - 190
Friction Angle	40° - 45°
Absorption (%)	3.6 - 14.8
Max Dry Density (kg/m^3)	1730

The MSW ash used in this study was obtained from the Pinellas County solid waste facility. According to the information provided by the County, the ash samples obtained were a combination of bottom and fly ash. This combined ash was stabilized using the WES-PHix process and was processed to a minus five inch size by removing the ferrous and non-ferrous metals to be recycled. Typically the ash generated from municipal solid waste incineration is land filled.

Upon first inspection of the as-received MSW ash samples, it was seen that the particle size ranged from large bulky materials (glass, ceramics, etc.) to fines. The appearance of the ash was mostly dark to light gray with the finer particles being lighter in color. Grain size distribution of the MSW ash was determined by sieve analysis in order to classify the material. Prior to running the sieve analysis, all of the large, bulky material was removed from the sample. A portion of the as-received sample is shown in Figure 3-1(a). This was done until the ash was allowed to pass a #4 sieve (4.75 mm). The sample was then dried and placed in the sieve shaker. A small portion of the sorted and dried ash used in the sieve analysis is shown if Figure 3-1(b). From the grain size distribution curve shown in Figure 3-2, it can be seen that the material classified as a poorly graded sand.



(a)

(b)

Figure 3-1: a) MSW Ash as Received b) After Sorting and Drying

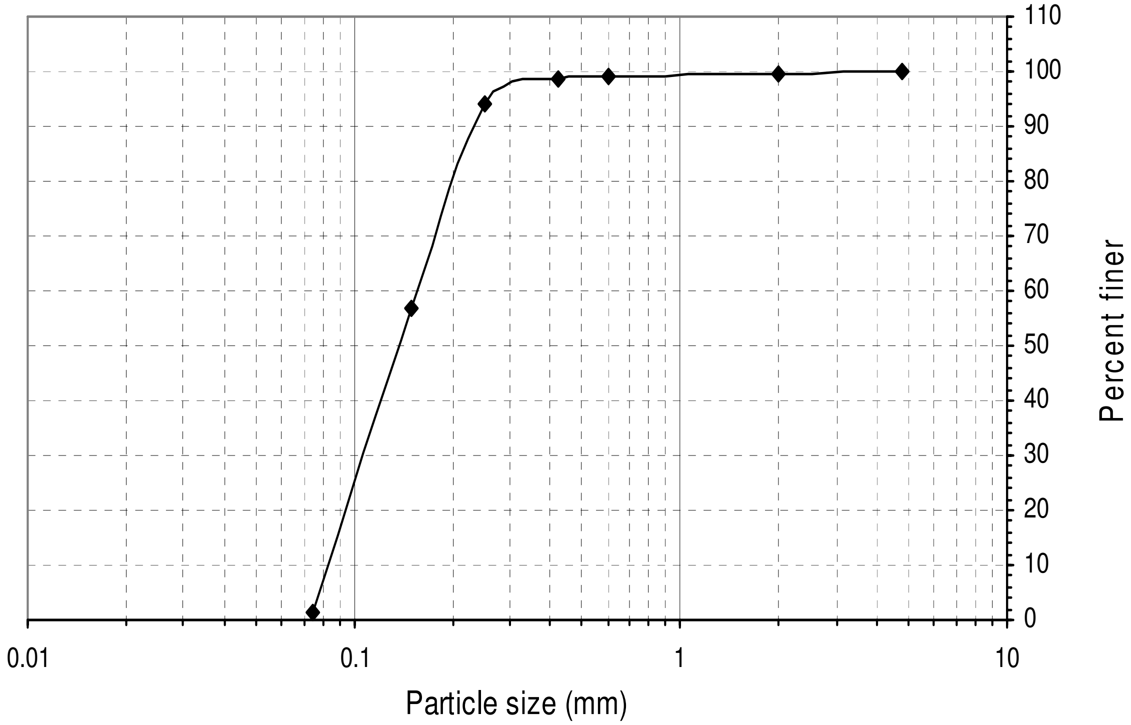


Figure 3-2: Grain Size Distribution for MSW Ash

Scrap Roof Shingles

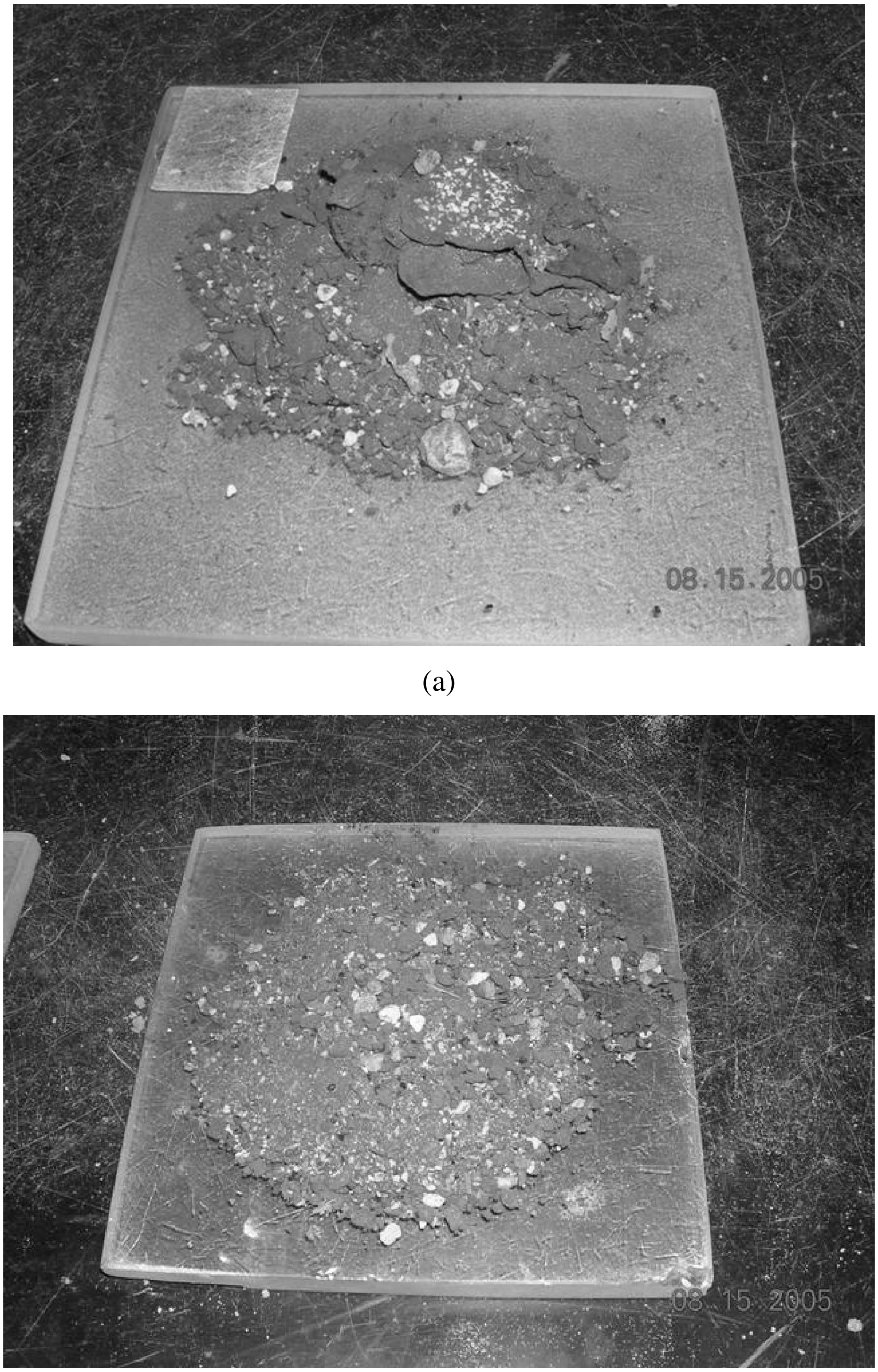
Roof shingle scrap maybe derived from two different sources, the first being the leftover material from roof shingle production. These are termed roof shingle tabs. The second, and more predominant source in terms of amount produced comes from shingle replacement and demolition projects. These are termed tear-off roof shingles. The major difference between shingle tabs and tear-off shingles is the variability of the final product. Shingle tabs, when collected, are uniform in their engineering and environmental properties. Tear-off shingles, on the other hand, are much more variable. This is mostly due to the fact that when tear-off shingles are collected, they will typically contain other materials such as nails, wood, and metals, mixed in with the shingle material.

Typically roofing shingles are made up of three major constituents: asphalt, fiberglass, and aggregate. As mentioned in the Literature Review, some states have used roofing shingle waste in limited recycling applications such as hot mix asphalt, however a large portion of shingles produced still ends up in the landfills (Hooper, 2004). The main environmental concern with reusing this material is the potential for the shingles to contain asbestos. In a study conducted by Hooper and Marr (2004) on moisture-density relationships and CBR values of scrap roof shingles, they looked minus 25.4 mm ground and screened shingle material. Their results are shown in Table 3-2. It should be noted that the shingle material used in the 2004 study were pre-consumer shingle tabs provided by the manufacturer.

Table 3-2: Compaction and CBR Data for Scrap Roof Shingles

Optimum Moisture (%)	7
Max Dry Density (kN/m^3)	15.7
CBR %	6
Swell %	0.5

The samples used in the current research were obtained from a roof shingle recycling plant in Hillsborough County. Similar to the MSW ash obtained, the particle sizes ranged from large bulky pieces to crushed fines. The samples also contained a number of foreign materials such as nails and pieces of wood. The as received shingles were mostly dry and dark gray to black in color and are shown in Figure 3-3(a). Similar to the MSW ash, the larger pieces of shingle were removed the material passing through a #4 sieve was subjected to sieve analysis. From the grain size distribution curve shown in Figure 3-4 it can be seen that the scrap roof shingles resemble a well graded sand.



(a)

(b)

Figure 3-3: a) Scrap Roof Shingles as-Received b) Screened Shingles

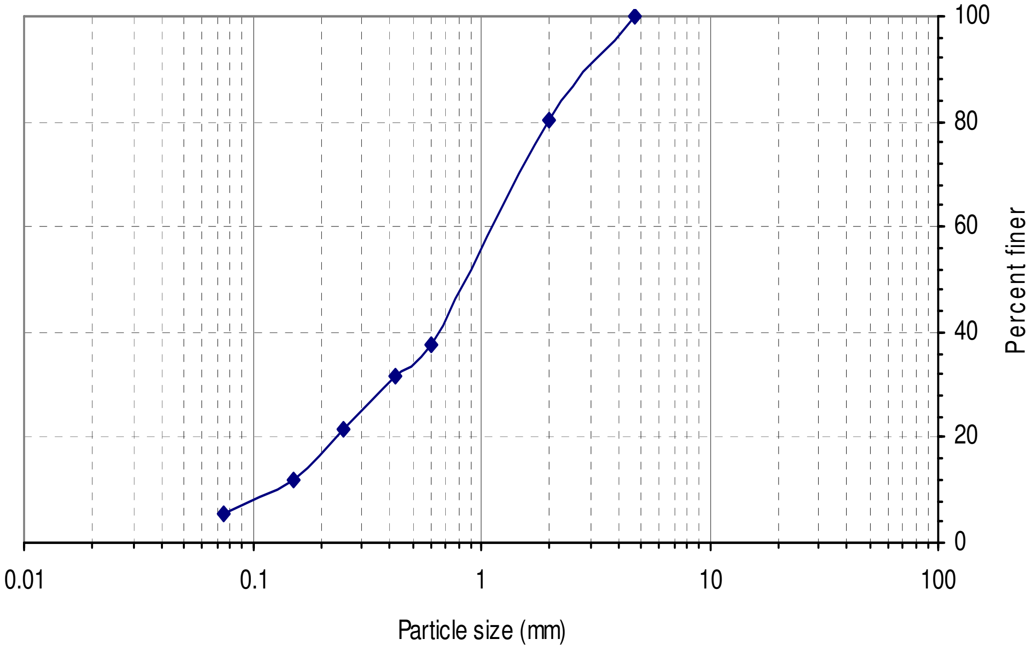


Figure 3-4: Grain Size Distribution for Scrap Roof Shingles

Paper Mill Sludge

Waste paper mill sludge, also termed fiber-clay when talking about reuse and recycling applications, is a major by-product of the paper manufacturing industry. There is a high residual of clay content in paper mill sludge due to the amount of kaolin clay in the manufacturing of paper products. Reported reuse applications for fiber-clay include landfill cover material, soil amendment for agricultural purposes, and as road bed material for remote access roads (Simpson and Zimmie, 2004).

Typically, paper mill sludge exhibits high water content and a low solid content. However, the material may be compacted to a low permeability, a desired property for landfill cover material. The environmental issues that arise with the paper mill sludge in geotechnical applications include the potential to leach hazardous materials. Similar to MSW ash, paper mill sludge is a highly variable material in terms of its chemical makeup. The engineering properties for this material shown in Table 3-3 represent values taken from the few studies previously conducted for paper mill sludge.

Table 3-3: Engineering Properties for Paper Mill Sludge

Specific Gravity	1.88 - 1.96
Plastic Index	191
Compression Index	1.24
Permeability (cm/s)	$< 10^{-8}$

The paper mill sludge used in this research was obtained from a paper mill manufacturing facility in Northeast Florida. The sludge was dark gray to black in color and exhibited a high water content. The physical appearance of the sludge closely resembled an organic clay. Atterberg limits were evaluated on the as-received sludge in order to classify the material. The liquid limit (LL) was determined using the fall cone test according to British Standards BS 1377. From the plasticity chart in Figure 3-5, it can be seen that the paper mill sludge behaves like a kaolin clay. The plasticity index (PI) for the material is right around 115 and plots directly on the “A” line on the plasticity chart.

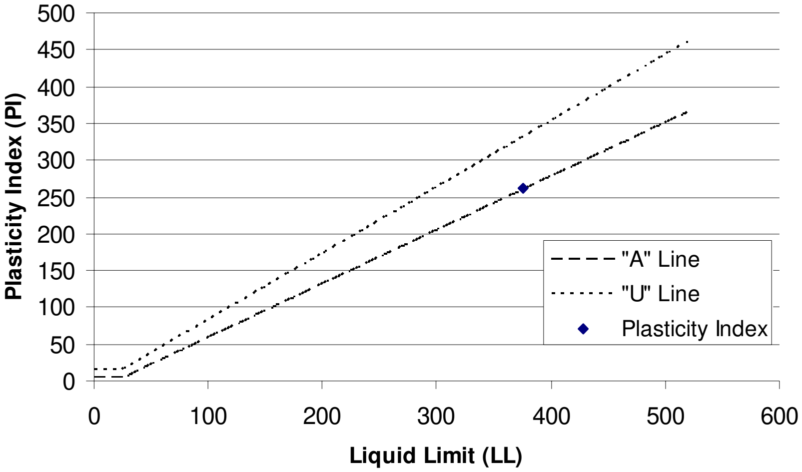


Figure 3-5: Plasticity Chart for Paper Mill Sludge

Scrap Tires

The last material considered in this research was waste scrap tires. Scrap tires come from any type of old truck or automobile. Scrap tires are typically land filled or incinerated for fuel. As mentioned in the literature review, scrap tires are one of the most extensively researched recycled materials. This extensive research has led to the generation of ASTM standards for reusing scrap tires in different applications including the ASTM designation D6270-98 "Standard Practice for Use of Scrap Tires in Civil Engineering Applications. Recycling applications include fill material and hot asphalt concrete (Consentino et al., 1995). The majority of reuse applications for scrap tires require processing of the material prior to reuse. Processing of tires basically consists of shredding the tires, removing the steel, and further shredding until the desired product is produced.

The tires used in the current research were obtained from a rubber tile manufacturing company in Hillsborough County. This company utilized scrap tires and processed them to a crumb rubber material comprised of very fine material. The samples obtained were relatively dry, completely uniform, free of any non-rubber material, and black in color. Reported engineering properties for scrap tires are given in Table 3-4.

Table 3-4: Engineering Properties for Scrap Tires

Unit Weight (kg/m^3)	390 - 584
Specific Gravity	1.1 - 1.3
Absorption (%)	2 - 3.8
Friction Angle*	19° - 41°
Permeability (cm/sec)	1.5 - 15
Young's Modulus (kPa)	770 - 1250

*Depending on how tires are processed i.e. shreds, crumb, etc.

Sand and Organic Clay

For the testing program of this project, described in detail in chapters 4 and 5 of this report, the materials described above were blended with either sand or organic material depending on the desired application. It is pertinent to describe these materials in this portion of the report.

The sand was obtained from a job site on the campus of the University of South Florida provided by the physical plant. The sand was fairly uniform with small pieces of lime rock existing throughout the samples. Sieve analyses conducted on the sand, shown in Figure 3-6 show that the sand may be classified as an A-3 material according to the AASHTO classification system.

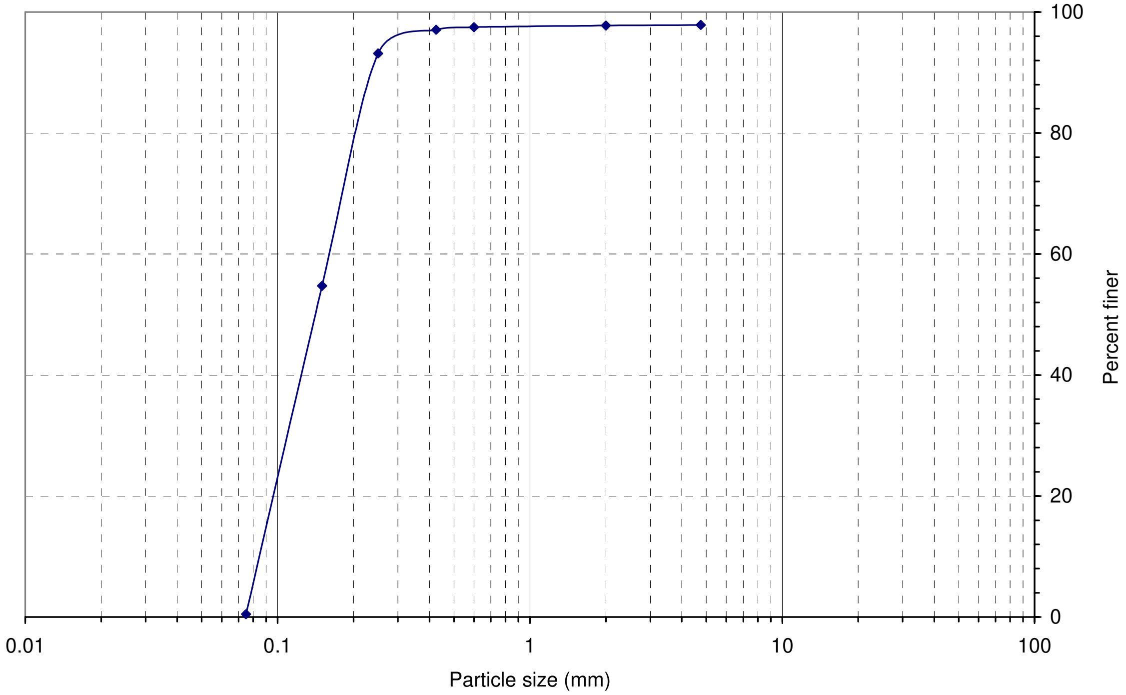


Figure 3-6: Grain Size Distribution for Florida Sand

The friction angle of the sand was determined by the direct shear test. This test was also conducted on sand samples blended with scrap roof shingles and is described in more detail in chapter 5. The results of the direct shear test in Figure 3-7 show the sand having a friction angle of 30^0.

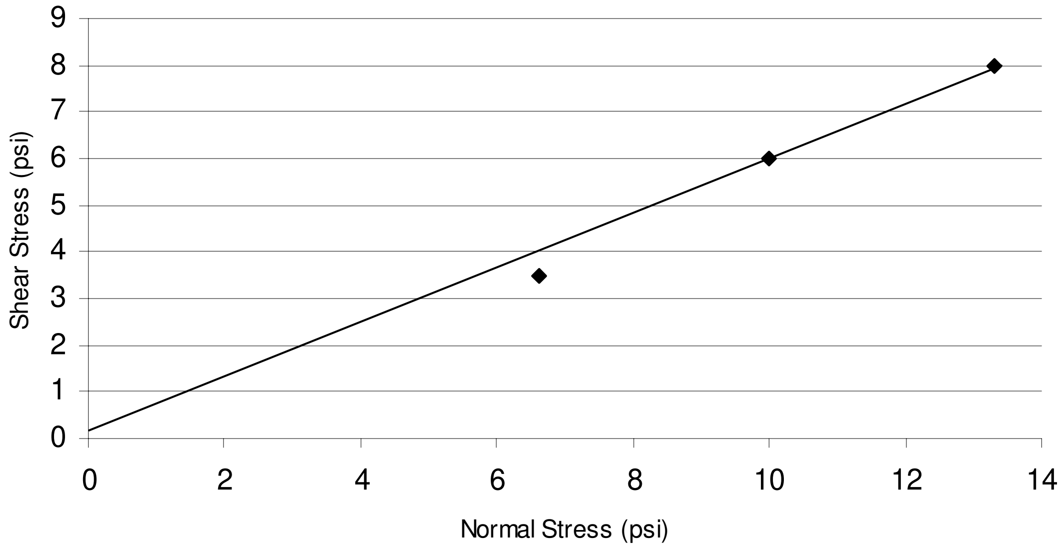


Figure 3-7: Direct Shear Test on Sand

The organic material was obtained from a dredging project site in Pinellas County provided by the city of St. Petersburg. Atterberg limits for the organic material were tested and the PI came out to a value of 94. The plasticity chart shown in Figure 3-8 shows that the material can be classified as an organic clay.

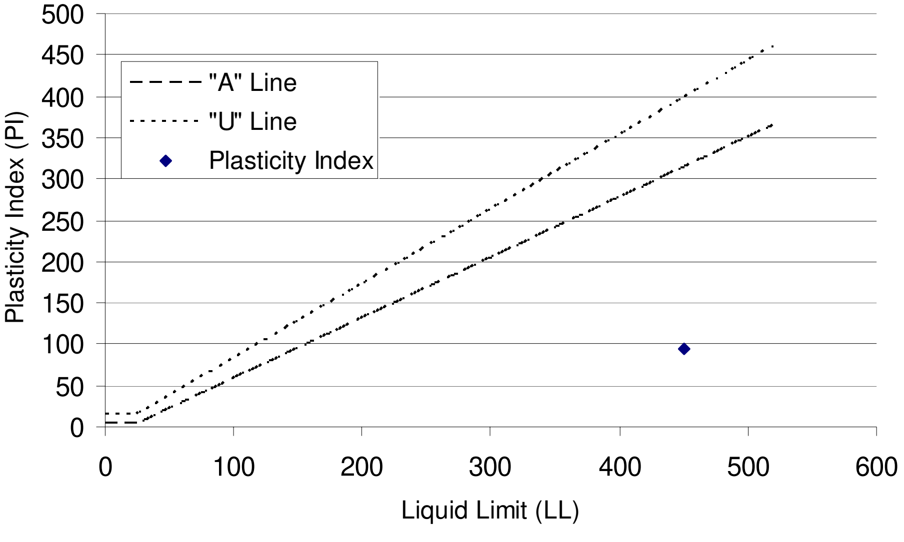


Figure 3-8: Plasticity Index for Organics

The effects of adding MSW ash to the plasticity of organic clay was investigated. Two mix ratios, 10% and 30% MSW ash by weight to organic clay were tested. The results are shown in Figures 3-9 and 3-10, respectively. The addition of MSW ash to the organic clay had a significant effect on the plastic index. Adding 10% MSW ash to the organics caused the plastic index to drop from 94 to 13. When 30% MSW ash was added, the plastic index dropped a little more to 10.7. From these results it can be said that the cementing effects of the MSW ash can change a very high plasticity clay to a medium plasticity clay.

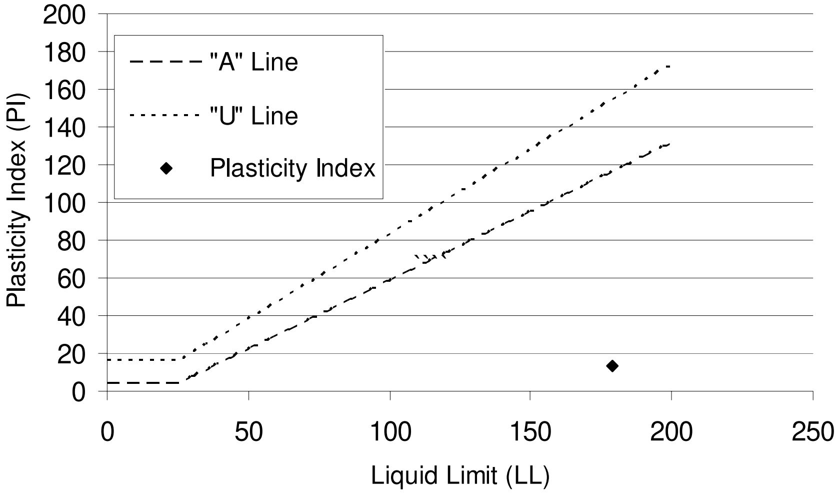


Figure 3-9 Plasticity Index for 10% MSW Ash and Organics

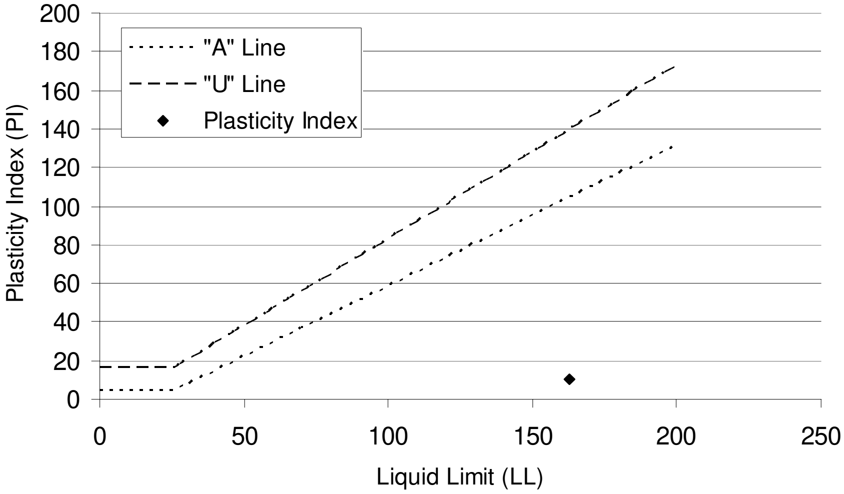


Figure 3-10: Plasticity Index for 30% MSW Ash and Organics

Chapter 4: Compaction Properties

Introduction

The principle behind compaction of a soil is basically using mechanical energy to increase the density of the material. When loose soils are compacted, there is an increase in the unit weight of the soil, which in turn leads to higher strength. It is also important to take into account the affect of the water content of the soil during compaction. Addition of moisture to soil will allow for the soil particles to slip over themselves and cause further densification than if the soil was completely dry. Adding more moisture to the soil will increase the strength to a point. After this point, any further addition of moisture will not lead to any more increase in strength. This point is called the *optimum moisture content.* The maximum dry density of the soil will occur at the optimum moisture content.

The major reuse applications for the materials considered in the current research are in the construction field. Therefore it is important to know how the addition of the recycled materials to soils will affect the compaction behavior. All the materials considered were mixed with the sand described in chapter 3 and subjected to compaction testing, in order to determine how they affect the optimum water content and maximum dry density.

Test Methods

The methods of compaction testing for all sand-recycled material samples were the same. Testing was done in accordance with the ASTM Standards under the designation: D 698-91 “Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort.” In this method a 4-in diameter mold that is 4.6-in in height without the extension was used along with a 5.5-lbf hammer dropped from a 12-in height. The mold was filled with 3 layers of soil each compacted using 25 blows from the hammer. After compaction, the extension was removed and the excess soil was trimmed from the top. The mold was weight in order to determine the unit weight since the volume of the mold is fixed at 1/30 ft^3. For determination of water content, the samples were dried in a bulk oven for at least 24 hours. A minimum of 6 trials were run for each sample in order to obtain the moisture content-dry unit weight curve.

Compaction curves for all tests run were plotted along with the zero air voids (ZAV) curve. The ZAV curve represents the theoretical maximum dry unit weight for a given moisture content. This maximum dry unit weight occurs when there is no air present in the void spaces. Test results and observations for the compaction behavior using each material are discussed in this chapter.

Results and Discussion

MSW Ash

MSW ash was mixed with sand and organic clay separately in varying percentages. Samples of 0, 1, 5, and 10% MSW ash by weight blended with were tested. In preparing the samples, the MSW ash was first screened and dried. The ash was then passed through a #4 sieve (4.75 mm). This fraction was then blended with sand by hand in the varying percentages mentioned above. The samples were blended until it visually appeared that the ash was uniformly spread throughout the sand. The ash-organic blends tested included 0, 10, and 30% ash by weight to organics. These samples were prepared similar to the sand samples.

The compaction curves for ash-sand blends are plotted in Figure 4-1. From the compaction curves it can be seen that the addition of MSW ash has an increasing effect on the maximum dry density of the sand. The sand alone (0% MSW Ash) shows a maximum dry density of 106.5 lb/ft^3. The addition of each percentage of ash led to an increase in maximum dry density. The largest increase occurred when 10% MSW ash by weight was added to the sand. This resulted in an increase of maximum dry density to 110 lb/ft^3. This increase in maximum dry density can be attributed to the pozzolanic nature of the ash material. In other words, the ash will react with the added moisture and cause a cementing effect, which in turn leads to increased strength of the soil. This effect should increase with increasing percentage of MSW ash content.

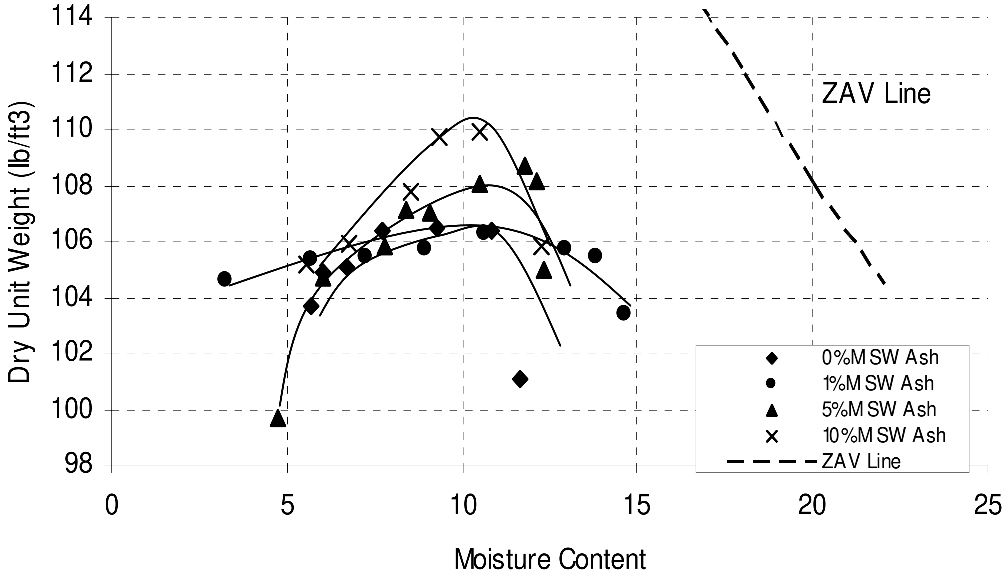


Figure 4-1: Compaction Curves for MSW Ash-sand Blends

The compaction curves for the ash-organic blends are shown in Figure 4-2. The curves show similar results to the ash-sand blends, although the effect is not as pronounced. The addition of MSW ash does show a slight increase in the dry unit weight of the organics and a decrease in the optimum moisture content.

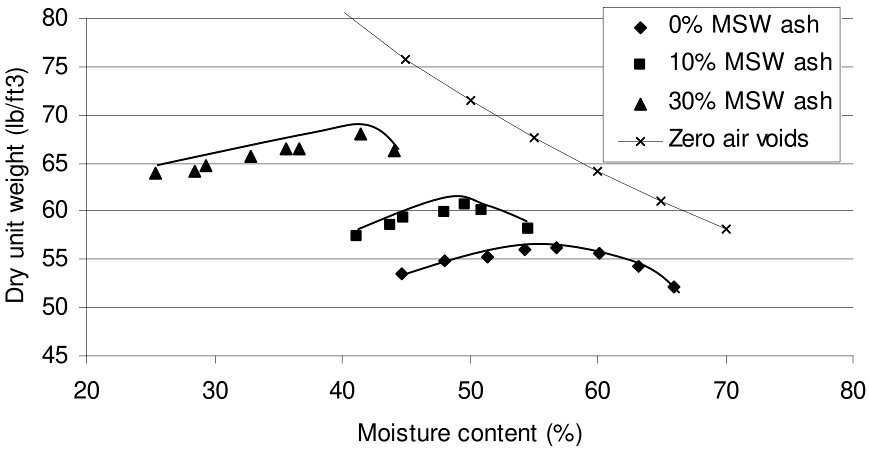


Figure 4-2: Compaction Curves for MSW Ash-organic Blends

Scrap Roof Shingles

The scrap roof shingle samples were mixed with sand in 0, 1, 5, and 10% by weight. The preparation of the samples was similar to the MSW ash. The results of the compaction tests are shown in Figure 4-3. From the plotted curves it can be seen that the addition of scrap roof shingles does not effectively result in any significant increases in the maximum dry unit weight of the sand. Addition of 1% and 5% shingles to sand had little to no effect on the maximum dry density. 10% addition caused an increase of 1 lb/ft^3 in maximum dry density. From these results it can be shown that scrap roof shingles do not perform well in soil stabilization through blending.

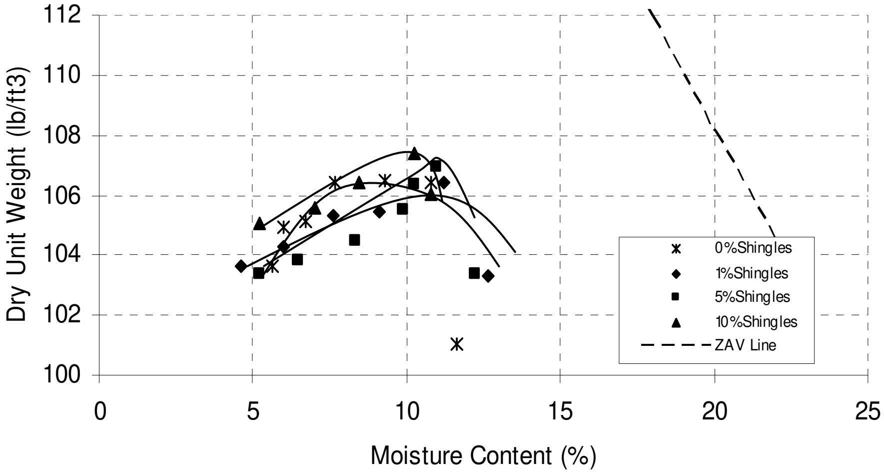


Figure 4-3: Compaction Curves for Scrap Roof Shingle-sand Blends

In addition to the effect on compaction behavior, the creep behavior of scrap roof shingles was also investigated. The creep test shows how the shingles would deform over time under a constant load. This behavior is important when considering a material to be used in roadway construction applications.

For this test two samples were analyzed: 100% dry sand and 100% dry scrap roof shingles. Each sample was compacted in a standard Proctor mold in three layers. Each layer was compacted with 25 blows from a standard Proctor hammer (5.5-lbf). The compacted samples were placed in a rack and a load hanger was placed on top of the sample. The apparatus of the test is shown in Figure 4-4.

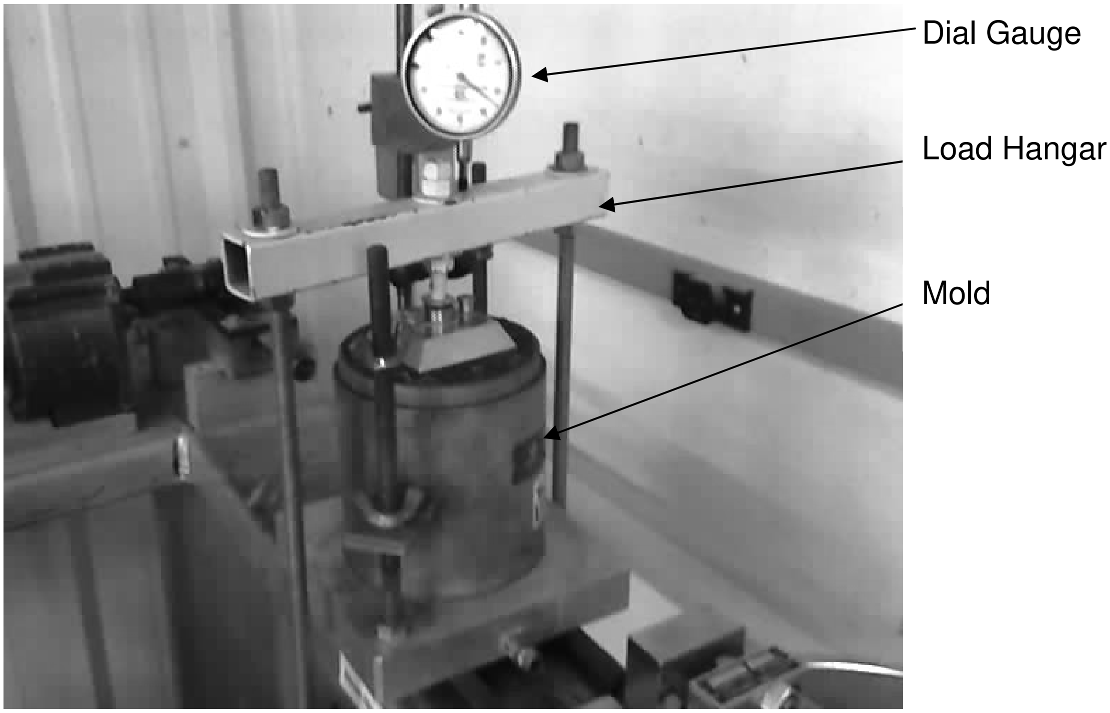


Figure 4-4: Creep Test Apparatus

Once the sample was compacted and placed under the load hangar the load was applied by adding weights to the bottom of the hangar. Two tests were conducted under different constant loads for each sample. Loads of 45 and 125 lbs were applied. Deformation was measured using a dial gauge placed on top of the load hangar. Results of the Creep tests were plotted and shown in Figure 4-5. The plot shows that, over time scrap shingles tend to deform much more than the sand.

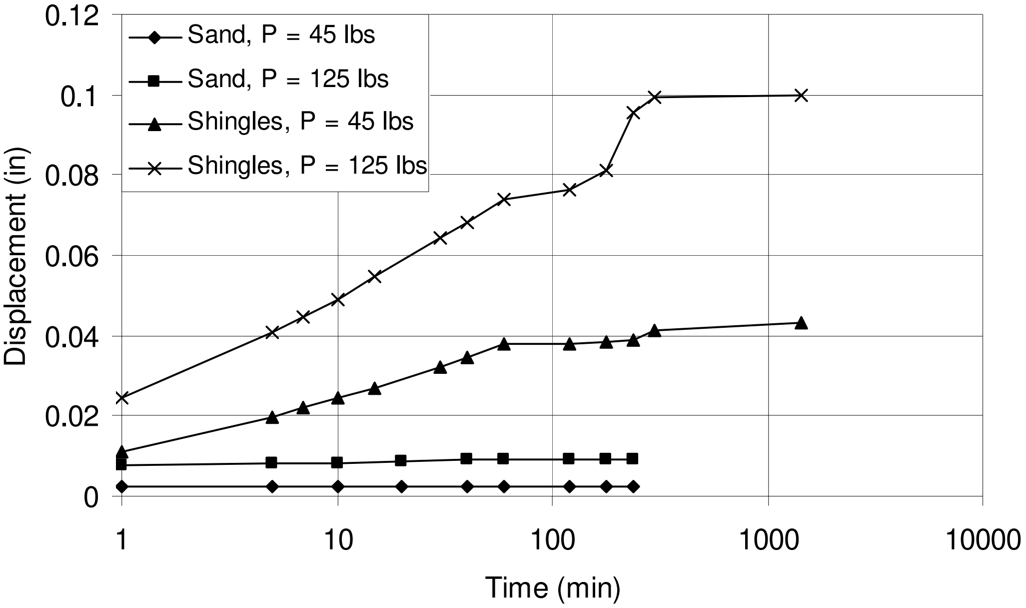


Figure 4-5: Creep Test Results

Paper Mill Sludge

The paper mill sludge required more preparation than the ash and shingles before it could be blended with sand. The as-received sludge was high in water content. The sample to be blended was first dried in an oven with the temperature not exceeding 60^0 C. The temperature was kept at this level in so that any organic material would not burn off. Once the sludge was dried out it formed into coarse clumps of varying sizes. The larger clumps were fairly easy to break apart but the smaller ones were much more dense and harder to break up. These smaller clumps needed to be pulverized using a particle crusher before they could pass the #4 sieve.

Once the sludge samples were screened they were blended with sand and subjected to compaction testing. The compaction curves are shown in Figure 4-6. Blends of 1% and 5% by weight paper mill sludge to sand were tested. From Figure 4-6 it can be seen that the addition of paper mill sludge led to a decrease in the maximum dry density of the sand. The decrease was more pronounced when 5% sludge was added compared to 1% sludge. For this reason a 10% paper mill sludge to sand blend was not tested.

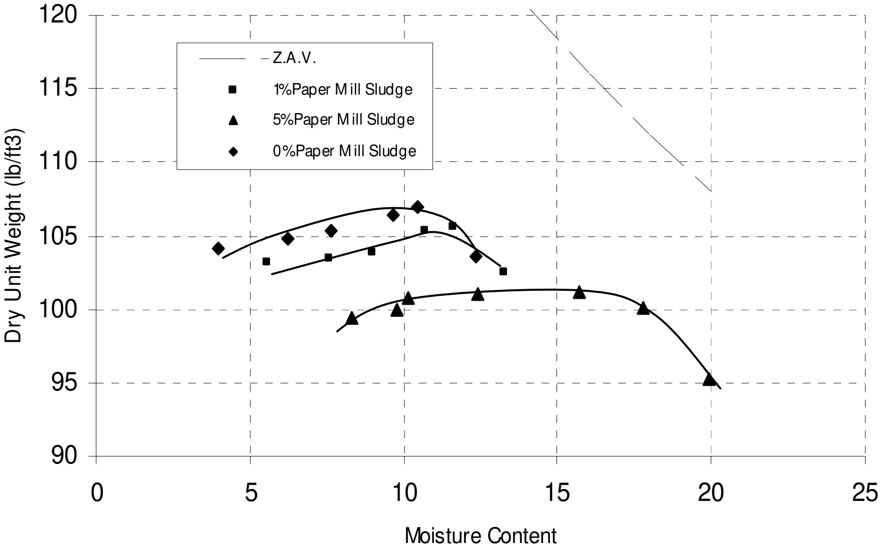


Figure 4-6: Compaction Curves for Paper Mill Sludge-sand Blends

Scrap Tires

The scrap tire samples received from the rubber tile manufacturer were in the form of crumb rubber. The crumb rubber was fairly dry and uniform as shown in Figure 4-7. The material did not require any preparation prior to blending with sand. Compaction testing was applied to 0, 1, and 5% crumb rubber tires by weight and sand blends. Compaction curves are presented in Figure 4-8.

The addition of crumb rubber to sand had a similar decreasing effect on the maximum dry density of sand. For this reason a 10% crumb rubber to sand blend was not tested.

Figure 4-7: Crumb Rubber

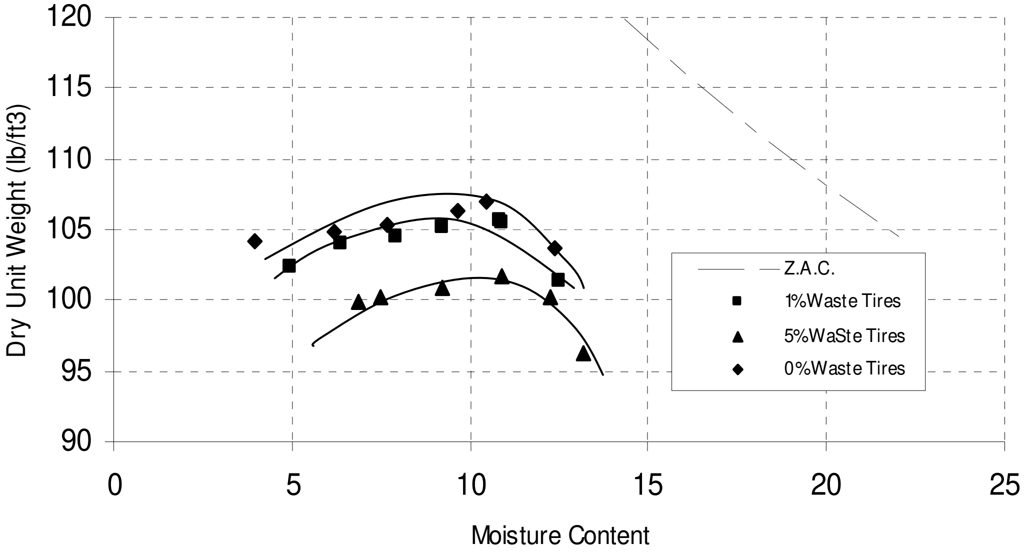


Figure 4-8: Compaction Curves for Crumb Rubber-sand Blends

Chapter 5: Shear Strength Properties

Introduction

The materials considered for the current research were subjected to a strength testing program when blended with soils. The materials tested such as MSW ash did improve the compaction characteristics of sand, however it is important to observe how this material can improve the shear strength of a weak soil that may be encountered in the field such as organic clay. In order to determine the effects of this material on the shear strength of organic clay, MSW ash was blended in and the samples were subjected to the unconfined compression test.

The other material that was tested for strength properties was scrap roof shingles. From the compaction testing, it was seen that adding scrap shingles to sand did have cause a slight improvement when blended with sand. In order to determine the strength characteristics of this material, the shingles were blended with sand and subjected to the direct shear test. This chapter describes the tests conducted and a discussion of the test results.

Unconfined Compression Test

The unconfined compression test was run on organic clay blended with MSW ash. The test was run in a triaxial cell mounted on a Loadtrac II load frame system. The samples tested included a 10% by weight MSW ash to organics and a 30% by weight ash to organics. The samples were mixed and under-compacted inside a cylindrical mold at their respective optimum moisture contents. The under-compaction technique involved increasing the number of blows with each lift. The optimum moisture contents were evaluated during the compaction testing. Blending of the materials was done by hand while both the ash and organics were dry and until the sample looked uniform to the eye. Water was added in small amounts and the sample was mixed until the desired moisture content was achieved. A split mold for preparing triaxial samples was used. The samples were compacted in the mold in 5 lifts using a tamper until the maximum dry unit weight was achieved. Once each sample was compacted, the mold was removed and the sample was placed in the triaxial chamber. The chamber was placed in the load frame and a strain rate of 2%/min was applied until the sample reached failure.

Each sample tested showed typical failure mode of a clayey sand rather than clay. The samples tended to shear diagonally rather then swell as shown in Figure 5-1. The results of the unconfined compression tests are shown in Figure 5-2.

The results indicate that adding MSW ash to organic clay has a slightly increasing effect on the unconfined compressive strength. The organic clay alone exhibited an unconfined compressive strength of 0.794 psi (5.47 kPa). Addition of 10% MSW ash increased the unconfined compressive strength to 0.866 psi (5.97 kPa). Adding 30% MSW ash did not cause any more significant increase in strength. The resulting unconfined compressive strength of the 30% MSW ash sample was 0.867 psi (5.98 kPa).

Figure 5-1: Typical Failure Mode for Organic Clay-MSW Ash Blends

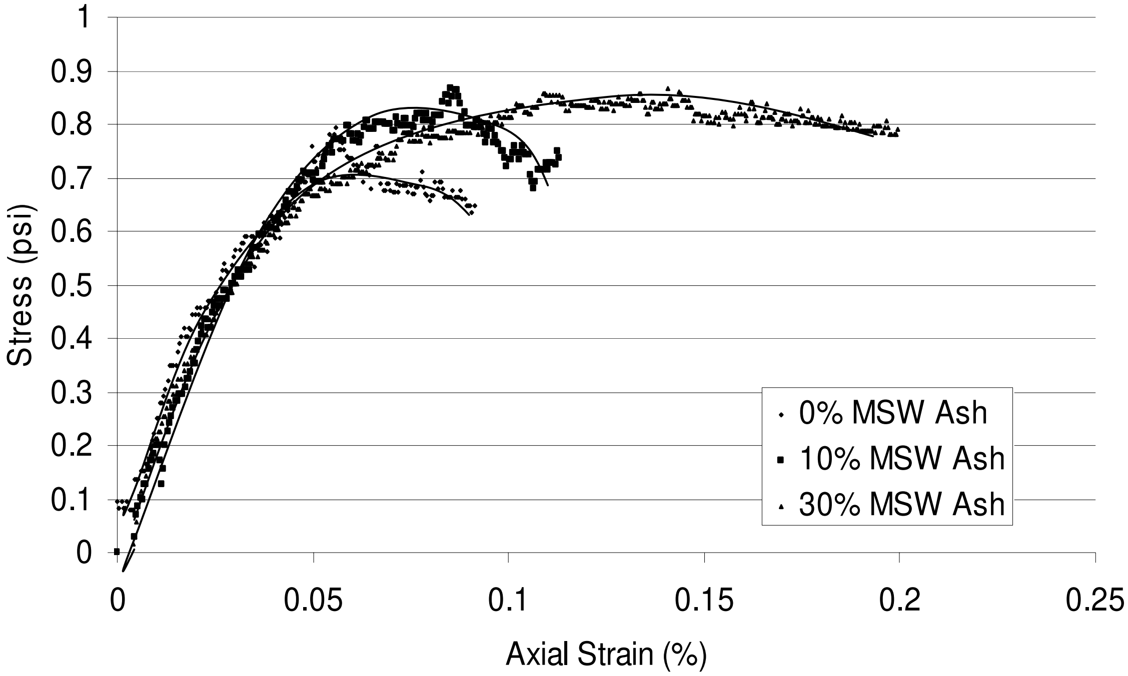


Figure 5-2: Stress-strain Curves for MSW Ash-organics Blends

Direct Shear Test

The direct shear test was conducted on the scrap roof shingles blended with sand. This test is provides a method for determining the shear strength properties and internal angle of friction for a given soil. For this test the sample is placed in a shear box with inside dimensions of 2-in by 2-in and a height of 1-in. The box is split in 2 halves top and bottom held in place with screws at each corner. The sample was placed into the shear box in 3 layers and compacted with a wooden tamper. Once the sample was compacted a normal load was applied by a load hanger and the box was placed in the direct shear test machine. The two halves of the box were then separated slightly by advancing the screws. A horizontal load was top half of the box at a constant rate of 1 mm/min. The load applied to the shear box was by way of a proving attached to the direct shear machine. Readings were taken every minute until the proving ring readings stopped increasing meaning that the sample had failed in shear. Displacement of the top half of the box was easily calculated since the load was applied at a constant rate of 1 mm/min.

The direct shear test was conducted on 3 different samples. The first was the sand with no shingles blended in. The second and third samples tested included sand blended with 5% and 10% shingles by weight, respectively. The samples were tested under 3 different normal loads of 35, 50, and 70 lbs. A plot of shear stress vs. displacement on the sample of sand alone is shown in Figure 5-3. Figures 5-4 and 5-5 show similar plots for the 5% shingles to ash and 10% shingles to ash samples.

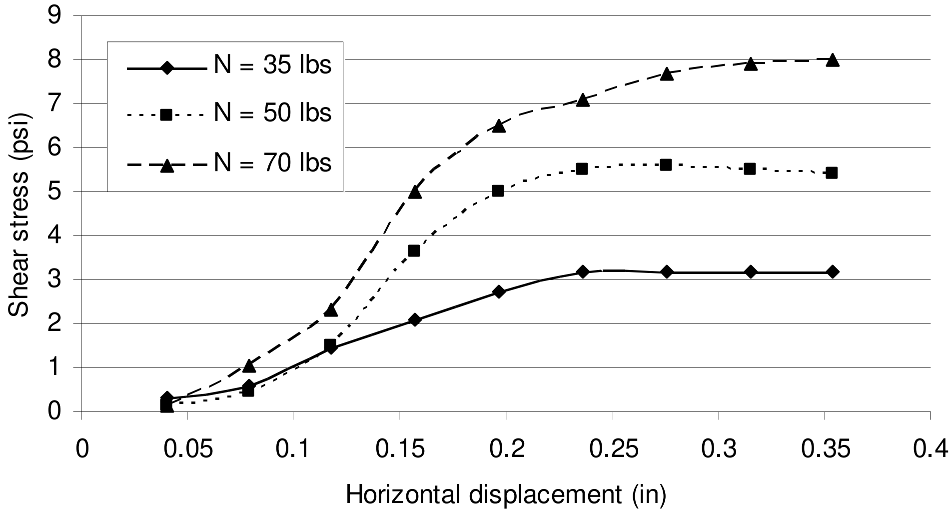


Figure 5-3: Shear Stress vs. Displacement for Sand

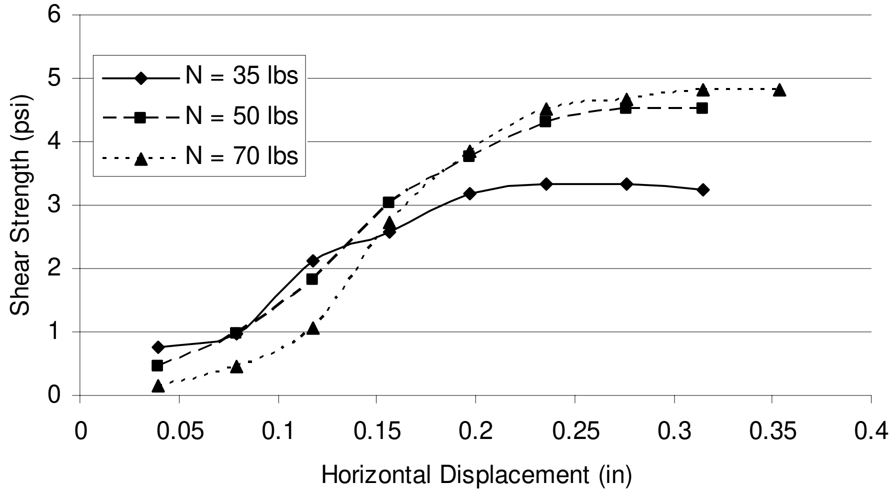


Figure 5-4: Shear Stress vs. Displacement for Sand and 5% Shingles

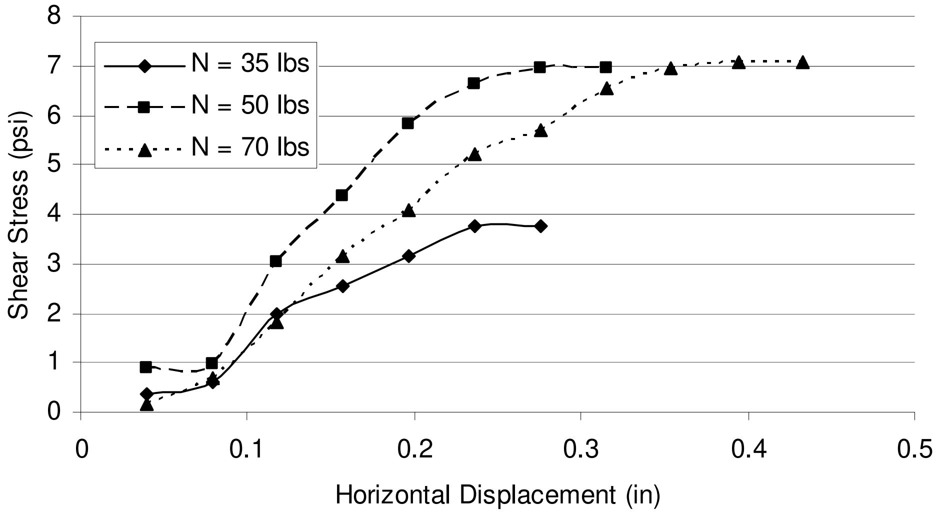


Figure 5-5: Shear Stress vs. Displacement for Sand and 10% Shingles

It can be seen from Figures 5-3 through 5-5 that adding scrap roof shingles had a decreasing effect on the shear strength at failure and little to no effect on the horizontal displacement of the sample at failure. For the sample of 100% sand, the peak shear stress under a normal load of 70 lbs is 8 psi and a displacement at failure of 0.35 in. When 5% scrap roof shingles are added to the sample the peak shear stress is reduced to 4.8 psi at the same displacement as the sand sample. When the amount of shingles added is increased to 10%, the peak shear stress reduced slightly to 7 psi and the displacement at failure was around 0.43 in.

The direct shear test also allows for the friction angle of the soil to be determined. For the shingles-ash samples tested the friction angle determination results are shown in Figure 5-6. From Figure 5-6 it can be seen that addition of shingles to sand had a decreasing effect on the friction angle of sand. The 100% sand sample showed a friction angle of 30^0. When 5% and 10% shingles were added, the friction angles reduced to 28^0 and 25.5^0 respectively. Overall, the results of the direct shear test on sand blended with scrap roof shingles showed that this material does not provide any significant effects on the shear strength of sand.

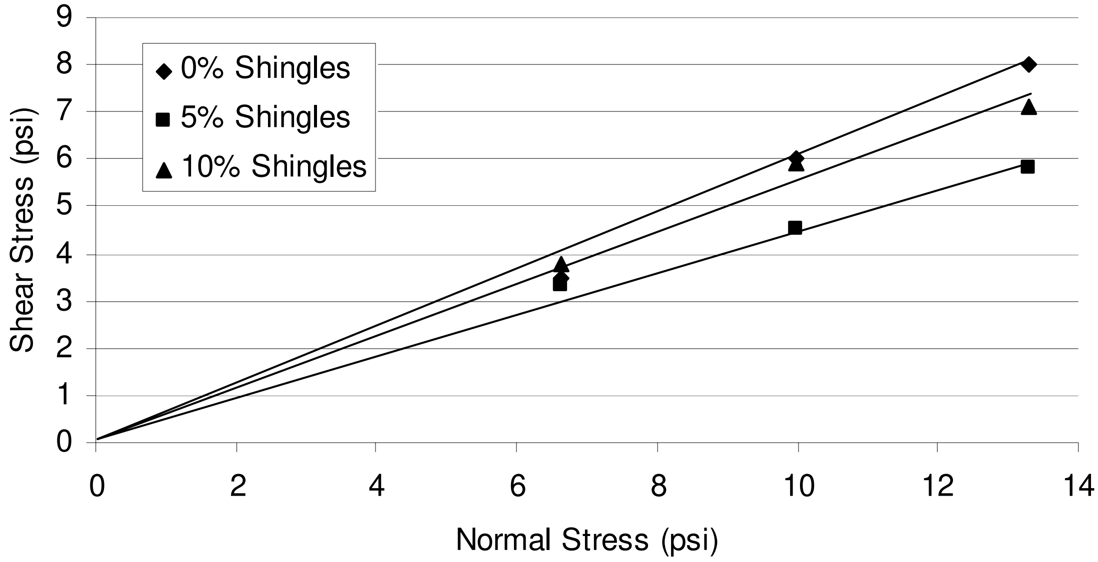


Figure 5-6: Effect of Shingles on Friction Angle of Sand

Chapter 6: Database Implementation

Introduction

Prior to the current research, many efforts have been made in trying to find other potential uses and applications for recycled materials. During the course of the literature review, it was found that the majority of the previous research conducted on recycled materials was published in various technical reports, online sources, and special publications. This makes it difficult for anyone interested in recycled materials applications to find any relevant information. As a result a project, in conjunction with the current research, was undertaken in order to organize all the available data on recycled materials research in a database. The database is being developed at the University of South Florida.

During the literature review potion of this project, information from all of the references including journal articles, conference proceedings, etc. were added to the database. This chapter will give an overview of the basic workings of the database and the process of adding and updating new data.

Overview of Database

The database is run using Microsoft Access software. The user is able to navigate through the database via a user friendly windows based interface. The starting screen of the database, shown in Figure 6-1, allows for the user to choose one of the following options: add or update existing data, query existing data, or maintain the tables within the database. These initial options allow the user to easily navigate through the database and quickly and efficiently find the desired information. The fact that the database is just as easily updatable ensures that the information taken is up to date with the most current research.

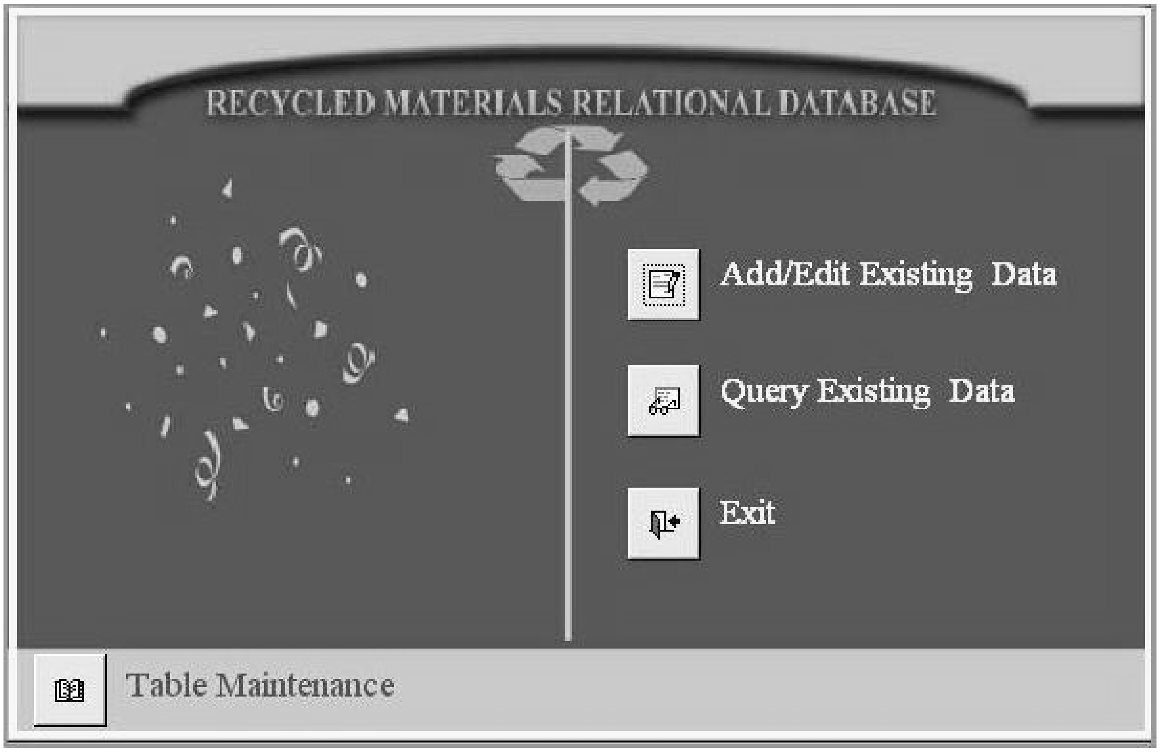
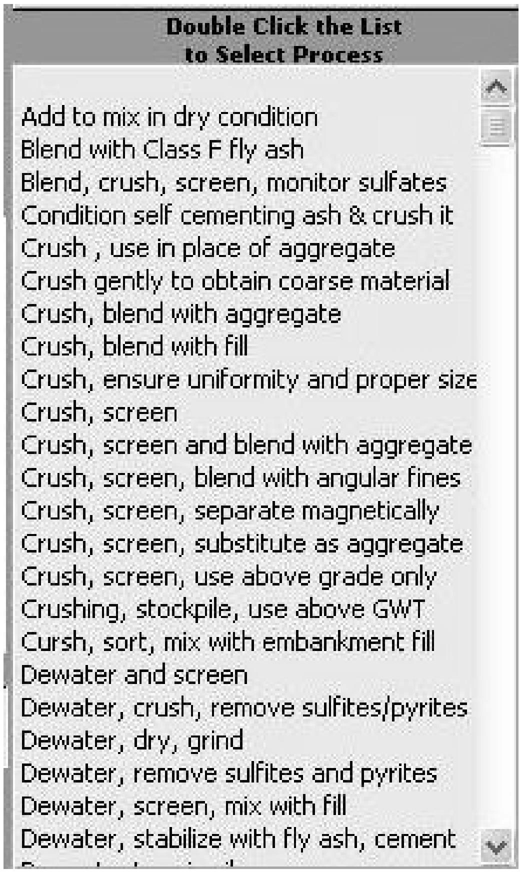


Figure 6-1: Recycled Materials Relational Database

Tables

The data is organized within the database via different related tables that include all the relevant information collected on the original 24 materials that showed potential for reuse applications. This list of materials is shown in Table 2-1. Along with the list of materials, there is also a list of processes that a specific material will undergo in order to produce a reusable form of the original material. These processes include a vast range of methods in which recycled materials are treated before they can be reused in a specific reuse application. Examples of the different processes include: crushing, dewatering, drying, screening, removing of foreign materials, etc. A portion of these processes can be seen in Figure 6-2.



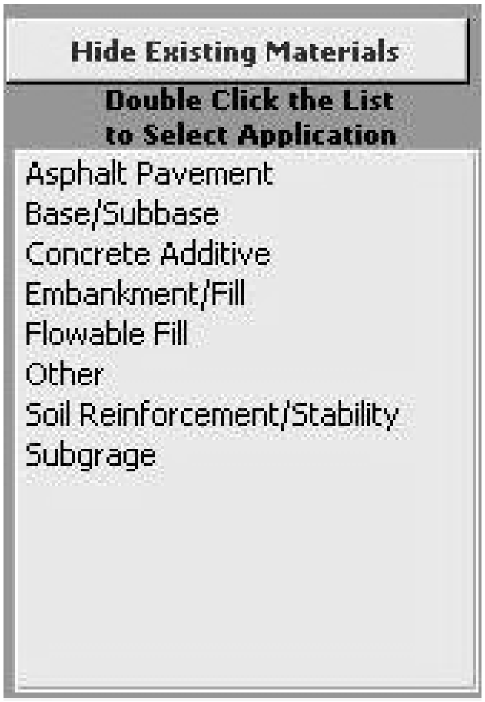
Add to mix in dry condition
Blend with Class F fly ash
Blend, crush, screen, monitor sulfates
Condition self cementing ash & crush it
Crush , use in place of aggregate
Crush gently to obtain coarse material
Crush, blend with aggregate
Crush, blend with fill
Crush, ensure uniformity and proper size
Crush, screen
Crush, screen and blend with aggregate
Crush, screen, blend with angular fines
Crush, screen, separate magnetically
Crush, screen, substitute as aggregate
Crush, screen, use above grade only
Crushing, stockpile, use above GWT
Cursh, sort, mix with embankment fill
Dewater and screen
Dewater, crush, remove sulfites/pyrites
Dewater, dry, grind
Dewater, remove sulfites and pyrites
Dewater, screen, mix with fill
Dewater, stabilize with fly ash, cement

Figure 6-2: List of Processes within Database

Other types of material specific information categories included in the database are: reuse application, engineering properties, chemical composition, organics content, metals content, leachate characteristics, the state in which the research was performed, and case studies. Each of these categories will be explained in more detail in the following sections.

Reuse Applications

This category includes several different potential applications for reusing recycled materials. For example, one of the potential reuse applications for recycled plastic is to produce plastic lumber and use this new material in a soil reinforcement/stability application. A list of the applications included in the database is shown in Figure 6-3. Other applications can be added to the database as they are found in the literature.

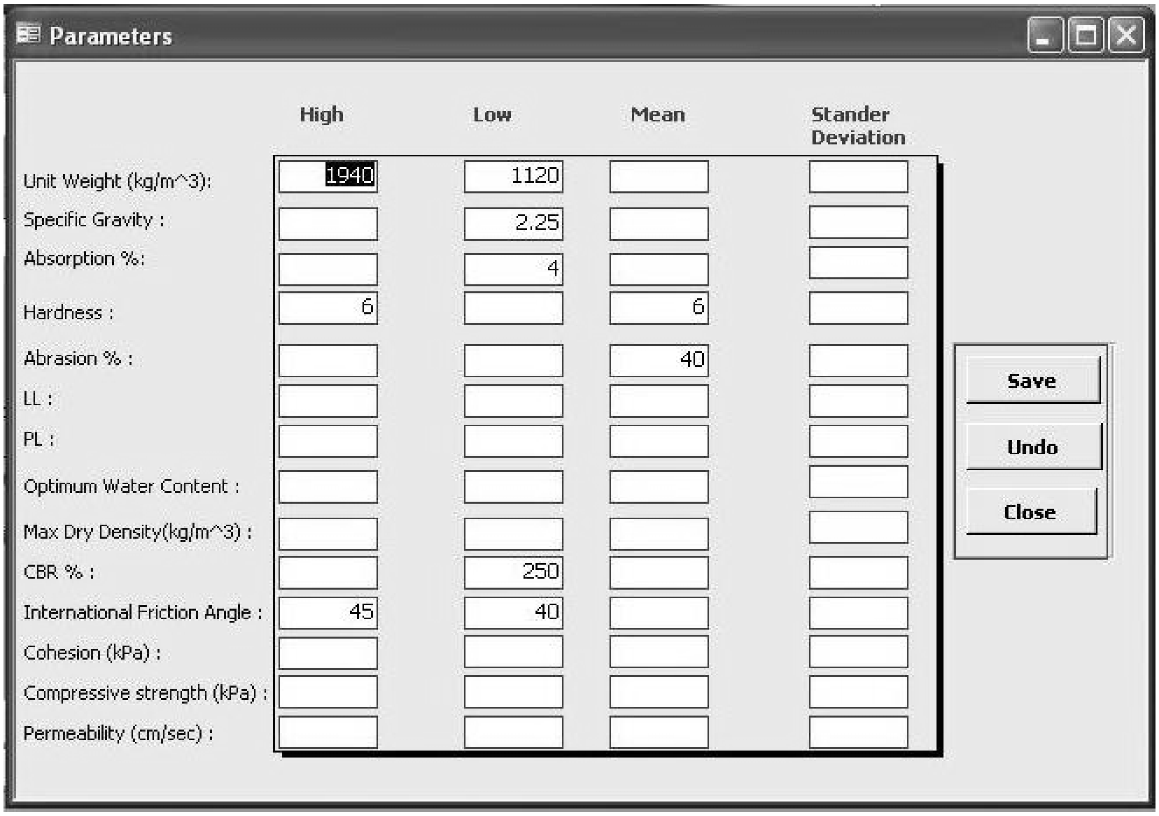


Asphalt Pavement
Base/Subbase
Concrete Additive
Embankment/Fill
Flowable Fill
Other
Soil Reinforcement/Stability
Subgrage

Figure 6-3: List of Applications within Database

Engineering Properties

This category consists of the basic engineering properties specific to certain materials. These properties include general geotechnical properties of the materials such as Atterberg limits (plastic and liquid limit), cohesion, and friction angle, etc. An example of the existing properties for scrap tires according to Yang et al., 2002, is shown in Figure 6-4. The engineering properties chosen to be part of the database were chosen based mostly on the ability of these properties to sufficiently describe a material. These properties are also consistently reported in papers focused on civil engineering applications for recycled materials.



	High	Low	Mean	Stander Deviation
Unit Weight (kg/m^3):	1940	1120		
Specific Gravity :		2.25		
Absorption %:		4		
Hardness :	6		6	
Abrasion % :			40	
LL :				
PL :				
Optimum Water Content :				
Max Dry Density(kg/m^3) :				
CBR % :		250		
International Friction Angle :	45	40		
Cohesion (kPa) :				
Compressive strength (kPa) :				
Permeability (cm/sec) :				

Figure 6-4: Engineering Properties for Scrap Tires

Material Composition and Leachate Characteristics

Along with lists of materials, applications, and engineering properties, the database also includes information specific to the chemical makeup and leachate characteristics specific to each material. Chemical composition for the materials is given in terms of percent weight of the material. Metal and organic concentration is given in mg/kg and the leachate parameters are in mg/L. A comprehensive list of all chemicals and compounds is available to characterize each material. The same goes for the metal and organic concentrations. However, if a chemical compound is noted in the literature but does not exist in the database, it can be easily added by way of the table maintenance option on the starting screen. Refer to Figure 6-1. Figures 6-5 through 6-7 show examples of the chemical compounds, metals, and organics included in the database.

		IDChem(	ChemCompound	ChemSymbol	selected
▶	+	1	Lime (Calcium Oxide)	CaO	☐
	+	2	Quartz (Silicon Dioxide)	SiO2	☐
	+	3	Alumina (Aluminum Oxide)	Al2O3	☐
	+	4	Magnesium Oxide	MgO	☐
	+	5	Iron Oxide	FeO/Fe2O3	☐
	+	6	Manganese Oxide	MnO/Mn2O3	☐
	+	7	Sulfur	S	☐
	+	27	Sodium Oxide	Na2O	☐
	+	28	Potash (Potassium Oxide)	K2O	☐
	+	48	Sulfur Trioxide	SO3	☐
	+	84	Calcium Sulfite	CaSO3	☐
	+	85	Gypsum (Calcium Sulfate)	CaSO4	☐
	+	86	Calcite (Calcium Carbonate)	CaCO3	☐
	+	95	Titania (Titanium Dioxide)	TiO2	☐
	+	96	Phosphorus Pentoxide	P2O5	☐
	+	98	Strontium Oxide	SrO	☐
	+	156	Silicon	Si	☐
	+	157	Calcium	Ca	☐
	+	158	Iron	Fe	☐
	+	159	Magnesium	Mg	☐
	+	160	Potassium	K	☐
	+	161	Aluminum	Al	☐
	+	162	Sodium	Na	☐
	+	177	Fluorine	F	☐
	+	180	Barium Oxide	BaO	☐
	+	182	Lead Monoxide	PbO	☐
	+	235	Chromium Oxide	CrO3	☐
	+	242	Boron Trioxide	B2O3	☐
	+	254	Polypropylene	Polypropylene	☐
	+	255	Nylon	Nylon	☐
	+	257	Styrene Butadiene Rubber	SBR	☐
	+	258	Carbon / Carbon Black	C	☐
	+	260	Zinc Oxide	ZnO	☐
✳		Number)			☐

Figure 6-5: Chemical Compounds Included within Database

		IDMetal	Metal	MetalSymbol	selected
▶	+	1	Barium	Ba	☐
	+	2	Cadmium	Cd	☐
	+	3	Chromium	Cr	☐
	+	4	Lead	Pb	☐
	+	5	Selenium	Se	☐
	+	6	Fluorine	F	☐
	+	7	Manganese	Mn	☐
	+	8	Iron	Fe	☐
	+	9	Zinc	Zn	☐
	+	10	Copper	Cu	☐
	+	11	Sodium	Na	☐
	+	12	Chlorine	Cl	☐
	+	14	Aluminum	Al	☐
	+	15	Calcium	Ca	☐
	+	16	Magnesium	Mg	☐
	+	17	Potassium	K	☐
	+	19	Arsenic	As	☐
	+	31	Silver	Ag	☑
	+	34	Beryllium	Be	☐
	+	43	Strontium	Sr	☐
	+	53	Mercury	Hg	☐
	+	66	Boron	B	☐
	+	69	Cobalt	Co	☐
	+	77	Molybdenum	Mo	☐
	+	79	Nickel	Ni	☐
	+	84	Titanium	Ti	☐
	+	85	Vanadium	V	☐
	+	132	Silicon	Si	☐
	+	343	Chromium (VI)	Cr (VI)	☐
*		(AutoNumber)			☐

Figure 6-6: Metals Included within Database

IDOrgCompound	OrgCompound	Volatility	selected
7	2,3,7,8,-TCDD		☐
8	1,3-Dichlorobenzene	Semi-Volatile	☐
15	Fluorine	Semi-Volatile	☐
18	Anthracene	Semi-Volatile	☐
24	Bis (2-Ehtylhexyl) Phthalate	Semi-Volatile	☐
25	Di-N-Octyl Phthalate	Semi-Volatile	☐
26	Benzo (b) Fluoranthene	Semi-Volatile	☐
31	Methylene Chloride	Volatile	☐
44	Toluene	Volatile	☐
49	Ethylbenzene	Volatile	☐
51	Bromoform	Volatile	☐
56	1,4-Dichlorobenzene	Semi-Volatile	☐
67	Fluoranthene	Semi-Volatile	☐
70	Benzo (a) Anthracene	Semi-Volatile	☐
81	Dichloroethane	Volatile	☐
82	Butanone	Volatile	☐
85	1,1,1-Trichloroethane	Volatile	☐
93	Dibromochloromethane	Volatile	☐
100	1,1,2,2-Tetrachloroethane	Volatile	☐
126	Trans-1,2-Dichloroethene	Volatile	☐
127	Methyl Tertiary Butyl Ether	Volatile	☐
134	Benzene	Volatile	☐
162	Pyrene	Semi-Volatile	☐
186	1,1,2-Trichloroethane	Volatile	☐
195	Phenols (Total)		☐
202	Acenaphthene	Semi-Volatile	☐
216	Benzo (a) Pyrene	Semi-Volatile	☐
224	Cis-1,2-Dichloroethene	Volatile	☐
227	1,2-Dichloroethane	Volatile	☐
229	Carbon Tetrachloride	Volatile	☐
245	1,2-Dichlorobenzene	Semi-Volatile	☐
246	Bis (2-Chloroisopropyl) Ether	Semi-Volatile	☐
247	Hexachloroethane	Semi-Volatile	☐
270	2-Butanone	Volatile	☐

Figure 6-7: Organic Compounds within Database

The leachate characteristics for the materials are given in terms of the reported results of environmental tests conducted. Results can be found within the database for such tests as the Toxicity Characteristic Leaching Procedure (TCLP) test, the Synthetic Precipitate Procedure (SPLP), the Extraction Procedure Toxicity Test, etc. The leachate tests within the database were chosen based on their ability to characterize a material as hazardous or not.

Updating Database

As mentioned in Chapter 1 of this report, the third task of this project was the updating of the database. During the course of the literature review, numerous journal articles and technical reports were compiled on past and present recycled materials research. The information not already included in the database was then added by way of case studies. A case study was basically a paper or report that entailed some form of characterization of a material that was included in original list.

This section describes the basic process of inputting a case study into the database. From the start screen (refer to Figure 6-1), the "Add/Edit Existing Data" option was selected. From here the user is given the options shown in Figure 6-8.

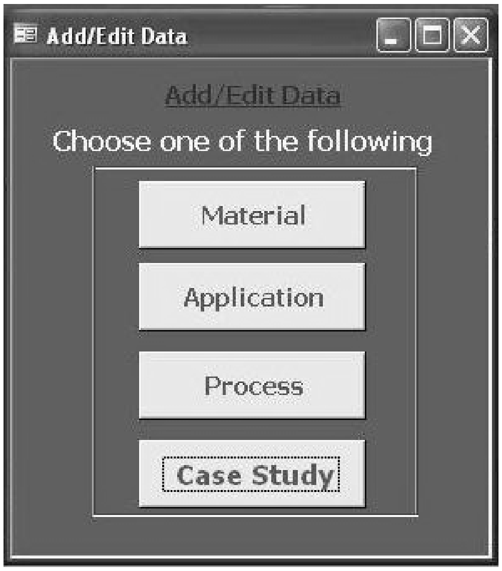
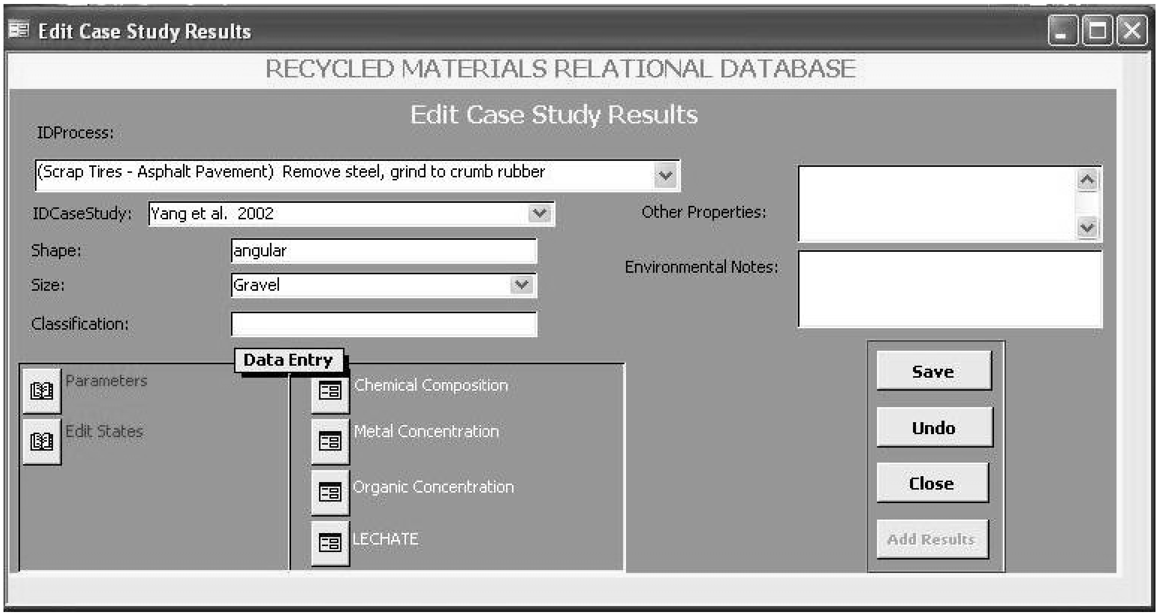


Figure 6-8: Adding Case Studies Process

From here the “Case Study” option is selected and the user is now able to begin adding preliminary information such as the author or authors, a full reference to the source, year of publication, and a general overview of what the source entails.

Once this preliminary information is inputted, it is saved and the user is taken to the screen shown in Figure 6-9. The screen shot shown in Figure 6-9 is taken from the inputted case study on scrap tires by Yang et al., 2002.



IDProcess: (Scrap Tires - Asphalt Pavement) Remove steel, grind to crumb rubber

IDCaseStudy: Yang et al. 2002

Shape: angular

Size: Gravel

Classification:

Other Properties:

Environmental Notes:

Figure 6-9: Inputting Case Study for Yang et al., 2002

At this point the user may now begin adding material specific information such as how the material is processed, what application the material is being processed for, engineering properties, chemical composition etc. It is important to note that for a certain material, multiple processes and applications may be chosen. This was the case for some of the materials researched where the material was considered for more than one reuse application or multiple materials were considered for a certain application. For example, Lee et al., 2002, recommended using a mix of fly ash and waste foundry sand as a fill of flowable back fill material. Both fly ash and waste foundry sand are also considered for reuse as separate materials.

Once this information is saved, it is now available to anyone with access to the database. If the need arises for a particular case study to be updated, it can be accessed through the screen shown in Figure 6-8. Instead of adding a new case study, the user is able to filter through all case studies within the database by author and year of publication. Once the desired case study is selected, the user is taken back to the screen in Figure 6-9, and the information can be updated.

Chapter 7: Conclusions and Recommendations

Conclusions

General Recommendations

The reuse of recycled materials in civil engineering applications is favorable because of the suitable engineering properties of the materials, the lower costs compared to traditional construction materials, and the fact that reusing these materials keeps them from being dumped into landfills. There are however, several issues and concerns that arise with the reusing waste materials.

The biggest concerns probably are the environmental impacts associated with reusing these materials. A good majority of the materials showing potential for reuse (Table 2-1) come from industrial waste sources. These materials will typically have some environmental concerns associated with reusing them in civil engineering applications. Materials such as phosphogypsum, may possess favorable engineering properties, but are not recommended for reuse due to unfavorable environmental properties, namely its radioactivity.

The flowchart shown in Figure 2-1 reiterates the importance of the environmental concerns of reusing waste and recycled materials.

Co-operation with such environmental regulating agencies such as the Florida Department of Environmental Protection (FDEP) and the Environmental Protection Agency (EPA) is essential with reusing waste and recycled materials. FDEP requires that a Beneficial Use Demonstration (BUD) is conducted before a material can be reused.

Materials Recommendations

As a result of this study, it is recommended that out of the 4 materials subjected to the testing program (MSW ash, scrap tires, scrap roof shingles, paper mill sludge), MSW ash was the only material that showed true potential for stabilizing soils by blending. The compaction and shear strength tests conducted showed that materials such as scrap roofing shingles had either little to no effect or even detrimental effects on the geotechnical properties the soils being stabilized.

MSW ash however showed that when blended with soils can have positive effects with respect to compaction behavior and shear strength characteristics. During compaction testing, the addition of MSW ash to sand resulted in an overall increase in the maximum dry unit weight of the sample. This can be directly connected to an increase in strength. The same result was achieved, although less pronounced, when MSW ash was blended with a marginal soil such as the organic clay used in the testing program. The addition of MSW ash to the organics had a more pronounced effect on the optimum water content of the organics which decreased by nearly 20% when 30% MSW ash by weight was added. The increase in strength as a result of blending soils with MSW ash is mainly attributed to the pozzolanic nature of the ash.

Recommendations for Further Research

Although, this study has shown that MSW ash can aid in stabilizing soils by blending, it also raises some questions that need to be addressed through further research. First and foremost is the environmental issue. A major problem with reusing MSW ash is the inconsistency of its chemical composition. The chemical makeup of MSW ash is variable due to the fact that the waste stream entering the combustion facility is not consistent. MSW ash composition can vary with location, type of combustion facility (Mass burn or RDF), and even the time of year when the ash is collected. This variability in composition is directly related to the question of whether or not MSW ash should be treated as a hazardous material. If MSW ash is going to be used as a soil stabilizer, it is recommended that it is closely monitored during processing and prior to blending with soils in order to make sure that no hazardous materials such as heavy metals leach out and get into the groundwater.

If MSW ash is recommended for use as a construction material on a given project, a report that can be accessed through the FDEP website, entitled "Guidance for Preparing Municipal Waste-to-Energy Ash Beneficial Use Demonstrations" provides guidelines for the user to conduct and submit a BUD to the FDEP. The purpose of the BUD is to provide verification that the ash being reused has been managed in such a way that its application will not violate air standards or surface or ground water standards and criteria. The BUD also ensures that the ash has been tested and monitored thoroughly prior to reuse.

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