ABSTRACT

SOLIDIFICATION/STABILIZATION OF PETROLEUM CONTAMINATED SOILS WITH COLD MIX ASPHALT CONCRETE

Nazhat Aboobaker

In this research Petroleum Contaminated Soils (PCSs) are recycled in Cold Mix Asphalt (CMA), to produce a useful product that can control potential environmental threats. The stability, durability, and hydraulic conductivity are three important engineering parameters that need to be considered when using petroleum contaminated soils (PCSs) in cold mix asphalt (CMA). In this research, stability, durability, and hydraulic conductivity due to the addition of six different PCSs into CMA is investigated. The stability test were performed to determine if cold mix asphalt made with petroleum contaminated soil can withstand heavy traffic. The freeze-thaw, and wet-dry tests were performed to determine the durability of petroleum contaminated soil in Cold Mix Asphalt. The hydraulic conductivity of cold mix asphalt with PCSs was evaluate to determine if the mix will contaminate the pavement system and also to evaluate the long term durability.

Equipment results show that CMA made with PCS has low good stability, sufficient durability and low hydraulic conductivity. Therefore, it can be used for paving roads with low traffic volume.

SOLIDIFICATION/STABILIZATION OF PETROLEUM CONTAMINATED SOILS WITH COLD MIX ASPHALT CONCRETE

by
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SOLIDIFICATION/STABILIZATION OF PETROLEUM CONTAMINATED SOILS WITH COLD MIX ASPHALT CONCRETE

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This thesis is dedicated to my loving
family, who supported me

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CHAPTER 1

INTRODUCTION

1.1 Statement Of Problem

The United States Environmental Protection Agency (USEPA) estimates that there are approximately 2 to 3.5 million underground storage tanks (USTs) throughout the nation, of which 25% are estimated to be leaking. Most of these tanks store gasoline and fuel oils. On an average, most of these tanks are 20 years old. Soils contaminated by leaking underground storage tanks are called Petroleum Contaminated Soils. Petroleum contaminated soil (PCS) is a solid waste. The availability of the solid waste disposal facilities are becoming limited with increasing governmental regulations. Land filling is considered the least attractive option when disposing a waste material. Thermal methods are too expensive and are known to create an environmentally unsafe conditions such as air pollution. Biological methods are cheaper but time consuming. Therefore, PCSs need economical and fast disposal techniques.

This research investigate the possibility of stabilization and solidification of petroleum contaminated soil by incorporating into cold mix asphalt concrete for use on secondary roads. The technology and use of cold mix asphalt concrete for paving using asphalt emulsion as a binder dates back to early 1940s. The cold mix asphalt concrete is made by mixing asphalt emulsions with virgin aggregates. The end product is spread, graded and compacted to form a strong asphalt concrete pavement. The mixing water in asphalt emulsion is evaporated to form asphalt concrete. The process of making cold mix asphalt concrete is a relatively economical and simple. It is conducted at ambient temperature, i. e., no heat is added. This tends to minimize volatilization of contaminate and associated air quality issues. The stabilizing medium used in the process is asphalt emulsion, containing water, surfactant, and shredded asphalt. During the curing process, hydrocarbon contaminants in PCSs will bind with asphalt rendering them environmentally unavailable. Asphalt emulsions are used in road construction and maintenance project in the United State for surface treatments, patching and thin overlays, structural stabilization, and slurry sealing. Asphalt emulsions are also used in base and surface course mixes and in pavement recycling. The purpose of asphalt emulsion is to disperse asphalt cement in water that will maintain liquidity for pumping, storage, and mixing. It will quickly break down on application and, on curing, to provide the adhesion, durability, and water resistance of the asphalt cement (USDOT, 1979).

The ratios of virgin aggregate, and cold asphalt emulsion can be changed to produce asphalt paving materials of varying physical properties. The recycling of petroleum contaminated soil into cold mix asphalt will turn a waste material that is potential environmental hazard into a valuable resource for the production of a useful product. The chemical constituents in petroleum contaminate soils, are basically similar to those in asphalt. In fact, asphalt is the residue from the petroleum refining process. Thus the addition of petroleum contaminated soil provides sand and gravel to reduce the amount of virgin sand and aggregate used in the process. In order to fully understand the process, the composition of asphalt emulsion and the function of aggregates in CMA are explained below.

1.2 Materials

1.2.1 Asphalt

Emulsified asphalt is a mixture of shredded asphalt cement and water. A small amount of a binding agent, (a surfactant) is added to this, heterogeneous system containing two normally immiscible phases - asphalt and water. In emulsified asphalt water forms the continuous phase, and minute globules of asphalt form the discontinuous phase. Emulsified asphalts are either anionic (electro-negatively charged asphalt globules) or cationic (electro-positively charged asphalt globules), depending upon the emulsifying agent. These two types are classified further depending on the rate of setting. Selection of the proper type and grade of asphalt material to use for each project is the most important aspect in the process. Meegoda, 1995 lists the selection criteria for asphalt emulsion to make CMA with PCS. Once the emulsified asphalt is mixed with aggregate it is cured to produce CMA. During curing water is evaporated and asphalt cement binds aggregate to form CMA. The relative curing rates of emulsified asphalt, depends on the environmental factors such as humidity, wind, the amount of rain, and the prevailing range of ambient temperatures of the region and mixing temperature.

1.2.2 Aggregates

A wide variety of aggregates and soil-aggregate combinations, ranging from well-graded crushed rock to silty sands, can be mixed satisfactorily with asphalt emulsion to produce cold mix asphalt concrete. Factors such as shape of aggregate particles, types and amount of fines, and differences in specific gravities of the mineral aggregates must be taken into account in producing strong and durable CMA.

Commercially, available crushed rock, slag, and gravel are used for cold mix asphalt. Well-graded, processed aggregates are always desirable for any of the asphalt pavement structure, but many poorly-graded and gap-graded aggregates have proven adequate for base course mixes when combined with the proper asphalt using good construction procedures.

1.3 Integrity of Asphalt Pavement

Asphalt paving mixtures typically are composed of aggregate and/or sand (90 to 95 percent by weight) and asphalt (5 to 10 percent by weight). The aggregate and/or sand is responsible for the primary load bearing properties, while asphalt serves as the binder and as a protective coating. The asphalt binder functions best when the aggregate/sand particles are fully coated with asphalt. If a particle is coated with water or a clay film prior to mixing, the liquid asphalt may cover the water or clay film, without directly adhering to the aggregate particle. The suitability of asphalt paving mixes are judged based upon high stability, high durability and low permeability.

Pavement stability is determined primarily by the friction between the aggregate particle, the viscosity of the asphalt mixture and the mix ratio of the asphalt to aggregate. Stability is enhanced by using aggregates with rough textured surfaces and may also be influenced by particle size and gradation. For high stability, the amount of asphalt should be minimized, as too much asphalt will act as a lubricant and cause the mixture to flow.

Durability, resistance to weathering, crushing and degradations, is partially dependent upon permeability. Durability is primarily dependent upon the aggregate sand resistance to crushing, abration and weather, and the asphalt resistance to weathering and aging. Permeability, to prevent water absorption. Low permeability is desired to resist the impact of weathering. Permeability is an important factor in durability. For high durability and low permeability higher asphalt content is required.

1.4 Advantages of PCSs in CMA

The asphalt concrete is made of asphalt emulsion, or cold mix asphalt concrete has been used extensively for paving roads and parking lots. The asphalt provides a flexible paving material which resists cracking and washout.

There are various advantages of the PCSs in CMA, are summarized below.

1. It does not produce significant emissions of hazardous hydrocarbon vapors into the air during the asphalt production process. As dryers are not needed to heat the aggregate, no emission of organics. The dust emission is always low. Emulsified asphalt does not produce objectionable fumes or odors.
2. The disposal of soil contaminated with petroleum in landfills is avoided, thus controlling future liability associated with landfills.
3. Approval for recycling is no more complex than approval for disposal at a landfill or for incineration.
4. The costs are competitive with those of current methods used for the treatment and disposal of soil contaminated with petroleum products.
5. A number of types and grades of emulsified asphalt are available to satisfy the varying requirements of different aggregates and weather conditions.

6. High production rates are possible with a comparatively low investment in equipment. A small investment in equipment is required for cold-mix construction, where large mixing plants are not available. The process of making CMA is simple and economical.

1.5 Limitations of Cold Mix Asphalt

Cold mixes also have the following limitations:

1. Weather: Cold-mix construction should not be performed when atmospheric temperatures is less than 10°C (50° F), or when rain is predicted. As the aggregate is not heated, its maximum temperature is limited to that of the atmosphere, plus that attributable to solar radiation. Upon application, the asphalt quickly reaches the temperature of the aggregate. If the water is too cold, mixing is difficult. Also, extra manipulation is required for volatilization of water in cool and humid conditions.
2. Surface Moisture: The determination for surface moisture is based upon the surface dry weight of the aggregates. Up to 3 (sometimes more) percent surface moisture may be required on the aggregate for successful mixing with emulsified asphalt and subsequent compacting of the mixture.
3. Application: Asphalt cod mixtures may be used for surface, base, or subbase courses if the pavement structure is properly designed. As a surface course, cold mix is suitable for roads with medium and light traffic. For base or subbase, it is suitable for roads with all types of traffic. However, it is seldom used, in urban surface courses and other heavy traffic areas.

4. Quality Control: Satisfactory pavements can be achieved with mixed-in -place cold mixes when proper attention is paid to the following; uniformly applied and mixed asphalt and aggregates, and uniform aggregate gradation. However, the production process for these mixes is generally more difficult to control than that made in cold mix asphalt plants.

CHAPTER 2

EXPERIMENTAL PROGRAM

2.1 Representative Soil Samples

Soil samples from six contaminated sites around New Jersey containing less than 3% total petroleum hydrocarbon were used in this program. The soil was obtained in weathered states. The soil samples from the six different sites were stored in a closed and cool environment to obtain representative samples for experiments. Table 1, shows the classification, the moisture content, and the contaminants level for the six soils, (Meegoda et at., 1993). The aggregates were obtained from the Newark Asphalt company, NJ. The Asphalt Emulsion SCC-h 1 (trade name), was obtained from Vestal Asphalt, Inc., Vestal, NY.

The petroleum contaminated soils (PCSs) consisted of various mixtures of sand and gravel (90% on average), silt and clay (10% on average), with petroleum product (2000 ppm on average). Some of the soil arrived with large unfractured stone contained with finer particles. These stone were separated before testing or sieving. The PCSs ranged from poorly graded sand to clay and, silt. Soil #1 or PCS # 1 contained a well graded sand, PCS # 2 a clayey silt, PCS # 3 a silty clay, PCS # 4 a poorly graded sand, PCS # 5 a silty sand, and PCS # 6 a poorly graded sand with silt.

The level of contamination was considerably below the three percent or 30,000 ppm, for petroleum contaminant soil, a level suggested by the state of New Jersey to be considered as a hazardous waste. The soils contamination levels ranged between 0.11-0.66% (1,100-6,600 ppm) and from 0.0025-0.15% or (25-1500 ppm) for gasoline. The degree of contamination for oil contaminated samples were determined by the soxhlet oil and grease extraction method (USPHS standard method for the analysis of water and waste water). The degree of contamination for the gasoline contaminated sample was obtained using a method reported by Meegoda, et al., 1989.

The coarse and fine aggregate received from the asphalt company were aggregates, sand, and stone dust. The coarse aggregate were dark irregular shaped crushed stone. Surface texture is considered to be more important than the shape of aggregates. The strength and durability are dependent on the aggregate shape and the surface texture. A smooth-round particle can be easily coated with asphalt cement but asphalt cement will adhere to rough-irregular stone firmly.

Sieve analysis for aggregates gradation and of Petroleum Contaminated Soils (PCSs) were determined by dry sieve method (ASTM D421) and by wet sieve method (ASTM D422). These methods were employed to obtain the relative particle size distribution of the different PCSs. The specific gravity (ASTM D854) was determined for each of the aggregate type and for six soils. The grain size distributions of six contaminated soils are given in Table 2.

2.2 Mix Design of CMA with PCSs

In a cold mix asphalt paving mixture, asphalt and aggregate are blended together in precise proportions. The relative proportions of these materials determines the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement. Emulsion asphalt concrete or cold mix asphalt concrete consists of asphalt emulsion (asphalt, water, and emulsifying agent) and aggregates. The mixing water in the asphalt emulsion after the compaction of cold mix asphalt concrete is evaporated to form asphalt concrete. A typical Cold Mix Asphalt (CMA) consist of 45% coarse aggregate, 45% fine aggregate, and 5% mineral filler. Coarse aggregate contains sizes as large as 1 inch, and fine aggregate contains size finer than 1 inch and retained on #200 sieve. Normally, aggregates passing the No. 200 sieve is limited between 2-10% of the total mixture. A ratio of 95% virgin to 5% contaminated soil is a reasonable figure in producing a quality CMA. The aggregate blend with the right proportion of asphalt cement determines the strength of the CMA. A control mix for comparison and six mixes containing each soil type were designed. The grain size distribution of all mixes are shown in Table 3.

When a sample paving mixture is prepared in the laboratory, it can be analyzed to determine its probable performance in a pavement structure. The analysis focused on four characteristics of the mixture and their influence. Those four characteristics are: 1) mix density, 2) air voids, 3) voids in the mineral aggregate, and 4) asphalt content.

2.3 Properties Considered in Mix Design

A good cold mix asphalt pavement functions well if it is designed, produced and placed in such a way as to give certain desirable properties. There are several properties that contribute to the quality of cold mix pavements. They include stability, durability, permeability, workability, flexibility, fatigue resistance and skid resistance. Ensuring that a paving mixture has these properties is a major goal of the mix design procedure.

2.3.1 Stability

Stability of a cold mix is the ability to resist shoving and rutting under load (traffic). Stability of a mixture depends on internal friction and cohesion. Internal friction among the aggregate particles (interparticle friction) is related to aggregate characteristics such as shape and surface texture. Cohesion results from the bonding ability of the asphalt. A proper degree of both internal friction and cohesion in a mix prevents the aggregate particles from being moved past each other by the forces exerted by traffic.

In general, the higher stability mixture will be obtained by the angular shape particles with rough surface texture. When aggregates with high internal friction characteristics are not available, more economical mixtures using aggregate with lower friction values can be used for roads with light traffic volume.

2.3.2 Durability

The durability of cold mix asphalt is its ability to resist factors such as changes in the asphalt, disintegration of the aggregate, and stripping of the asphalt films from the aggregate. These factors can be the result of weather, traffic, or a combination of the two.

A higher asphalt content increases durability because thick asphalt films do not age and harden as rapidly as thin films. Thick asphalt films retains their original characteristics longer. Also, maximum asphalt content effectively seals off a greater percentage of interconnected air voids in the pavement, making it difficult for water and air to penetrate. Of course, a certain percentage of air voids must be left open in the pavement to allow for expansion of the asphalt in hot weather, and densification of asphalt concrete due to traffic.

A dense gradation of sound, tough, strip-resistant aggregate contributes to durability in three ways. A dense gradation provides closer contact among aggregate particles. This enhances the permeability of the mixture. A sound, tough aggregate resists disintegration under traffic loading; and stripping-resistant aggregate resists the action of water and traffic, by not stripping the asphalt film off aggregate particles. Stripping lead to raveling of pavement.

2.3.3 Permeability

Permeability is the resistance of an asphalt mix to the passage of air and water through it. This characteristic is related to the void content of the compacted mixture, and much of the discussion on voids in the mix design sections relates to permeability. Even though void content is an indication of the potential for passage of air and water through a pavement, the type of these voids is more important than the number of voids. The size of the voids, whether or not the voids are interconnected, and the access of the voids to the surface of the pavement all determine the of permeability of CMA.

2.4 Stability of PCSs in CMA by Marshall Mix Design

The purpose of the Marshall Method is to determine the optimum asphalt content for a particular blend of aggregate. The method also provides information about the properties of the resulting asphalt cold mix and establishes optimum density and void content that must be met during pavement construction. The Marshall Method uses standard test specimens of 2.5 inch height and 4 inch diameter. A series of specimen, each containing the same aggregate blend but varying in asphalt content, is prepared using a specific procedure to mix and compact the asphalt aggregate mixtures. The Marshall test (ASTM 1559-82) is applicable only for laboratory design and is used in testing hot and cold mix asphalt. The maximum size of aggregate that is allowed in this test is 1 inch. The two principal features of the Marshall Method of mix design are a density-voids analysis and a stability flow test of the compacted test specimens.

Tests were performed to evaluate the strength and flow of Cold Mix Asphalt with petroleum contaminated soil. Before the stability test the bulk specific gravity, which determines the volume of mineral aggregate (VMA), density and air voids in a sample are measured. The VMA is the voids in the mineral. This value is usually shown as a percentage and generally decreases with increasing percent of asphalt up until a minimum VMA is reached and then the volume of mineral aggregate starts to increase. Air void calculation is also expressed as a percentage and it usually decreases with increasing asphalt content. The optimum asphalt content is determine by finding asphalt contents at maximum stability, maximum unit weight and minimum VMA.

2.4.1 Marshall Test Setup

A partially automated Marshall testing apparatus with a linear variable differential transformer (LVDT) and a load cell was used in the study to collect and evaluate data from stability tests. A LVDT was employed to measure the deformation of a sample; load cell was used to determine the maximum compressive force (stability) of a given asphalt concrete specimen. To perform the various tasks associated with the test, a microcomputer was used together with a data acquisition board and a signal conditioner. During specimen testing, compression data was automatically displayed on a computer screen using the data acquisition program, Acquire. The compression equipment was setup to apply a diametrical deformation at 2 inches per minute

2.4.2 Preparation of Marshall Test Specimens

The same aggregate blends as those used for Hot mix asphalt with PCSs were used in this research (Meegoda et at., 1992). Based on the aggregate blending calculations the sieved aggregate of various different sizes were collected and store along with the petroleum contaminated soils (PCSs). Aggregate were divided into different groups based on their relative sizes. Each sample contained a certain percentage of the different sized aggregates; the total aggregate mixture would weight approximately 1200 grams. Table 3 shows the percentages of aggregates used for the control and six mixes with PCSs. To find the optimum asphalt content, 15 samples were prepared with five different percentages of asphalt cement. Three specimens had 4.0% asphalt, three had 4.5% and so on, increasing by 0.5% up until an asphalt content of 6.0%. All specimens were tested to find the best mix at which the asphalt concrete would achieve it maximum strength without affecting its durability.

Predetermined amount asphalt cement based on the asphalt content needed is added in the mixture. Then the PCS and aggregate mixture with asphalt is mixed for 1 minute. Then the mixture is spaded into the mold. This mold along with its base plate and collar is placed on a pedestal where compaction takes place. A filter paper was placed at the bottom of the mold to prevent the mixture from sticking to the base plate. The plastic mixture is spaded 15 times around the inner perimeter of the 4 inch diameter mold with a spatula 10 times over the interior. The material is slightly mounded with the mold before another filter paper is placed on top of asphalt mixture. At this point a 10 pound hammer is placed on top of the mold and dropped 75 times form a 18 inch height. The collar is removed along with the base plate from the mold so the mold can be rotated 180 degrees. The equipment is reassembled and another 75 blows are delivered to the mix making a specimen that is approximately 2.5 inch thick and 4 inch diameter. The mold with CMA is placed inside an oven at 60^0 C (140^0 F) for 4 days for curing. The specimen is extruded from the mold and is left in oven till tests were performed.

2.4.3 Marshall Test Procedure

There are three test procedures in the Marshall test method. They are: a determination of bulk specific gravity, measurement of Marshall stability and flow, and analysis of specimen density and voids content. After bulk (ASTM D-2726) and theoretical (ASTM D-3203) specific gravity are determined, the sample can be tested for strength, and flow.

To find the stability and flow, the Marshall test apparatus is used to compress the specimen. A typical Marshall test result is shown in Figure 1. The graph displays the deformation on the X-axis and the compressive load on the Y-axis and the load at which the specimen fails (stability), and the deformation at that point (flow). The flow value indicates whether paving mixes will experience permanent deformation or premature cracking under traffic loads. Marshall stability test results for control mix and six PCSs shown in Table 4, and summarized in Table 5.

2.5 Durability of PCSs in CMA

To determine the durability of a specimen, the freeze-thaw and wet-dry methods were employed. These tests are used to evaluated if asphalt concrete matrix can withstand harsh weather and does not have accelerated aging beyond the normal aging process. It measure the effect of moisture damage on asphalt concrete. This test measures the tensile strength ratio. The tensile strength of a moisture conditioned specimen are compared to the tensile strength ratios of the control specimens. Higher tensile strength ratio after freeze- thaw cycle and wet-dry cycle are required for petroleum contaminated soils in cold mix asphalt to withstand harsh environmental conditions.

The wet-dry and freeze-thaw tests (ASTM 4867-88) were conducted using the asphalt concrete mixture with PCSs having optimum asphalt contents. This method is used to test asphalt concrete mixtures in conjunction with mixture design testing. The control specimen was also tested with the optimum asphalt content. Table 5, shows the optimum asphalt for the control and six mixes with PCSs.

2.5.1 Freeze-Thaw Procedure

Six specimens are usually prepared for this test. These six specimen are divide into two subsets. Three specimen for moisture condition testing and three for dry conditioning. The specimen bulk and theoretical specific gravity as well as the air voids are determined. The aggregates were assumed to be non-absorptive. Store the three specimens that are to be dry conditioned at room temperature. The other three specimens are partially saturated to a value between 55% to 80% with distilled water using a vacuum chamber. Any specimen that is above 80% saturation is discarded. Wrap the partially saturated specimens tightly in two layers of plastic using masking tape. Then put specimen in leak proof plastic bags with 3 ml of distilled water. Seal and mark the specimen out of freezer at -18 ^{0} C. After at least 24 hour, take the specimen out of freezer and place it in a bath at 60^{0} C for three minutes out so the specimen can thaw for three minutes. Then take specimens out of bath, remove the bags and plastic coverings, and gently place the specimens back into the bath for another 24 hours. After the freeze-thaw procedures, measure the specimen in air and than in water again to determine the bulk specific gravity. Determine the height (ASTM D-3549), volume (ASTM D-2726), and swell. Swell is calculated using the initial specimen volume. Place moisture conditioned specimens along with the dry conditioned specimens in the bath for 30 minutes. After the 30 minutes, perform the tensile test to obtain the maximum tensile load.

Calculate the tensile strength as shown below:

$$St = 2 * P / (\Pi * t * D)$$

where:

St = tensile strength, psi

P = maximum load, lbs

t = specimen height, in

D = specimen diameter, in

Calculate the tensile strength ration as shown below:

$$TSR = (Stm/Std) * 100$$

where:

TSR = tensile strength ratio, %

Stm = average tensile strength of moisture condition subset, psi

Std = average tensile strength of the dry conditioned subset, psi

2.5.2 Wet-Dry Procedure

Six specimen are also prepare in the same way such as in the freeze-thaw procedure. The same procedures were followed for compaction, and testing as it is in the previous sections. The only difference with these procedure from that of the freeze-thaw test is that the specimens are not place in the freezer instead it is place in an oven at 60^0 C (140^0 F) for 24 hours. After the bulk and theoretical specific gravity are determined, the specimens are placed in a convection oven at a temperature of 60^0 C (140^0), for 24 hours. After 24 hours, specimens are removed from oven and placed in a water bath at a temperature of 60^0 C for another 24 hours. Follow the same procedures that is given in the previous section to find the tensile strength. The swell, tensile strength, and tensile strength (TSR) are also determine in the same way as in the freeze-thaw section.

2.6 The Permeability of PCS in CMA

The property of water-bearing formation that relates to its pipeline or conduit function is called hydraulic conductivity, k , and defined as the capacity of a porous medium to transmit water. It is expressed in velocity units, i.e., centimeter per second (L/T). Hydraulic conductivity is governed by size and shape of the voids, the interconnection between voids, and the physical properties of the permeating fluid. The volume of water passing through an asphalt concrete is restricted when there are limited amount of tubes. Since the physical properties of water very with temperature, the hydraulic conductivity is reported at a particular temperature. For CMA concrete, the asphalt content and amount of air voids may be an indication of the hydraulic conductivity of the concrete. For both soil and CMA concrete, the most significant contributor to the hydraulic conductivity is amount of interconnected voids and their access to the surface. High air permeability accelerate the oxidation process by exposing asphalt cement to air. Imperviousness to air and water is a necessity for durability of asphalt concerts. Therefore, permeability is one of the most important engineering factors in design of cold mix asphalt pavements

The hydraulic conductivity of porous medium is determined using two different experimental methods, constant head and falling head. In this research, falling head method is used to determine the hydraulic conductivity of CMA concrete.

2.6.1 Specimens Preparation

The average hydraulic conductivity value from three specimen is reported for each mix. The preparation and compaction is the same as in the Marshall test procedure. The specimen bulk and theoretical specific gravity are determined as well as the air voids. The Darcy's law is based on the assumption that medium is saturated. Hence, the hydraulic conductivity of a porous material should be determined only under saturated conditions. In this experiment, a back pressure of 30 psi was applied to facilitate saturation.

2.6.2 Equipment Setup

The testing equipment includes two portions, (a) chamber cells, (b) control panel. The schematic sketches of these two parts are shown on Fig 2 and Fig 3. After setting up the specimen inside the cell, we connect cell to the control panel. The procedures for setting up this equipment are shown below.

2.6.3 Chamber Cell

1. Place porous stone on top of the base plate.
2. Place a filter paper and the specimen on top of the porous stone
3. Place another filter paper and a porous stone on top of the specimen and then place the upper cap on top of that.
4. Check the membrane for leaks by placing air blown membrane inside a water bath.
5. Place the rubber membrane over the specimen, cap, and base plate. Make sure that the membrane completely covers both the cap and base plate.
6. Place O-ring to the base plate and to the upper cap.
7. Position the cylinder of the permeameter cell around the specimen.
8. Place the top plate on the cylinder and fasten the permeameter by tie rods.

2.6.4 Control Panel

1. To fill cell with desired water, connect the bottom plate and position B with a tube. Release the chamber pressure by means of another tube to top plate. Turn the switch A to "Fill".

2. After the chamber is filled with water, transfer the tube from position B to position O. Remove the tube from the top plate.
3. Connect position P and R by a tube; same as position Q and S.

2.6.5 Permeability Test Procedure

In this experiment, we determine the hydraulic conductivity of CMA concrete by means of measuring the volume of water transmitted through it. The volume of water can be easily measured by the permeability test apparatus shown on figure 2 and figure 3 . We can adjust the chamber, inlet, and outlet pressures separately and read the volume in each using standpipes on the control panel. The pressure is supplied by an air compressor. The three major procedures of falling head hydraulic conductivity testings are discussed below.

1. Pressure settings: Turn on the air compressor and check the supply pressure gauges on control panel of the permeability test apparatus. Use regulator 1, 2, 3 to adjust the pressure of each standpipe, chamber, inlet, and outlet. In this experiment, Cell pressure has been set to 50 psi (344 kPa), inlet pressure to 31 psi (213 kPa), and outlet pressure to 30 psi (20 kPa). The cell pressure was large enough to present leaking from sides.
2. Remove air from all the tubes and set the water level in each standpipes; highest at inlet and lowest at outlet.
3. Permeability test: Turn the switch F to "pipette" and G & H to "annulus". Open valves L, M, N, R, S. Let water flow through the specimen. Record the volume changes in three standpipes. Adjust the pressures on inlet and outlet standpipes based on the velocity of the flow through the specimen. Reset the water level in three standpipes.

4. Measurements: Record (1) time, (2) temperature, (3) outlet, inlet, chamber pressure in psi, and (4) water levels intake standpipe continuously during the test five times a day.
5. Termination of testing: Twenty-four hours after the in-flow became equal to the out-flow, and when the hydraulic conductivity did not show a further reduction, the permeability test was stopped.
6. Disconnect all the tubes and place another three sample for next test.

2.6.6 Data Collection and Calculation

During the test, five readings were taken each day. After the permeability test was stopped, the following equation (Chuang, l. u., 1993) was used to compute the hydraulic conductivity values.

$$k = \frac{a\,L}{2\,A\,t} * \ln\left(\frac{h_1}{h_2}\right)$$

where a (cm^2) is the cross-sectional area of standpipes; L (cm) is the average height of CMA specimen; A (cm^2) is the cross-section area of CMA specimen; t (sec) is the time interval between two consecutive readings; h_1 and h_2 (cm) each expresses the hydraulic head, including pressure head and elevation head at beginning and end of the time period. Finally, the hydraulic conductivity, k , is calculated and expressed as centimeter per second.

The variation hydraulic conductivity with time, graphs were plotted to show reduction in hydraulic conductivity due to saturation. When the hydraulic conductivity reaches the lowest value with no further reduction in time, it was assumed that the sample was saturated and the hydraulic conductivity values are reported.

CHAPTER 3

TEST RESULTS AND DISCUSSION

3.1 Stability Test Results

Marshall strength of control mix and six different PCSs is shown in Table 4. The Marshall stability test indicate that the CMA with PCS is strong enough to be used in low volume roads, i.e., 500 lbs of Marshall stability. Control mix and all PCS have Marshall stability greater than 500 lbs of Marshall stability, except PCS #1. The Flow values of all specimens of control mix and mixes with PCS have value greater than 6. The optimum asphalt content for a mix is usually determined using the average of asphalt contents corresponding to maximum stability, maximum density and minimum VMA. Meegoda, 1995 showed that CMA made with optimum mixes produced low durabilities. Therefore, in this research it was decided to increase the designed optimum value by a small fraction to obtain mixes that have higher durabilities but at reduced stabilities. The optimum value of asphalt was chosen 0.5% greater than the optimum value of Marshall stability for better durability of CMA. The optimum asphalt contents for control and six mixes with contaminated soils are as following : PCS #1-5.25%, PCS #2-5.0%, PCS #3-5.75%, PCS #4-5.25, PCS #5-5.0%, PCS #6-5.75%, and 5.5% for control mix. Table 5 shows the dry density, Marshall stability, air voids, VMA and flow values corresponding to the above optimum asphalt contents for the control as well as for CMA made with each soil type. The CMA with PCS #3 has stability value close to the control mix, while PCS #1 has the lowest value. It is interesting to note that mix with PCS #1 produced the best HMA mix (Meegoda et at, 1993).

3.2 Durability Test Results

Table 6 and Table 7 show the Durability test results, Wet-Dry and Freeze-Thaw test, for the control mix and CMA made with six PCSs. The percentage swell and the TSR are used to evaluate the durability of each mixture. The tensile strength ratio (TSR %) values and % Swell of Freeze-Thaw tests are comparable to the control sample. The freeze-thaw TSR values of PCS #5 and PCS #6 are marginal at 50%. Similarly, the freeze-thaw swell values of mixes with PCS #5 and PCS #6 are high. As expected, the TSR values of wet-dry test are better than these for freeze-thaw test. TSR values for CMA with PCSs are close to control mix, indicate that CMA with PCSs can produce durable asphalt concrete. The wet-dry TSR value for mix containing soil #5 and the freeze-thaw swell value for control mix produced unusual values. These tests need to be repeated. Except for mix with soil PCS #5, the percentage swell and TSR values of wet-dry test are comparable to those of control mix.

3.3 Permeability Test Results

Table 8 shows the average saturated hydraulic conductivity data for control mix and CMA with six PCSs. A good cold mix asphalt pavement will have a lower hydraulic conductivity to provide a better service life. All the hydraulic conductivity values are higher than 1.0 E -5 cm/sec. These values are higher than these obtained from the same HMA mixes. The 50% moisture in the asphalt emulsion may be contributing this higher hydraulic conductivity values. When the cold mix asphalt is cured this water is evaporated creating additional voids. This void fraction is almost similar to the void fraction occupied by the asphalt cement. This is the main reason in having much higher air voids when compared with HMA mixes. A hydraulic conductivity value of 1.0 E -5 cm/sec is considered to be a low value and hence is acceptable for pavement construction.

CHAPTER 4

SUMMARY AND SUGGESTION FOR FUTURE RESEARCH

Many companies have used cold mix technology to stabilize and solidify petroleum contaminated soils with asphalt emulsions, however there is no data on strength, durability, and other engineering properties of asphalt concrete. The process is relatively economical solution to soil contamination problems. The process is conducted at ambient temperature, this tends to minimize contaminate volatilization and associated air quality issues. This research study was conducted to evaluate the design parameters for asphalt pavement, and mechanical properties of cold mix asphalt concrete with petroleum contaminate soils. This research shows that petroleum contaminated soil can be stabilized and solidified by incorporating it into a CMA for use on secondary roads.

In this research commercially available asphalt emulsions were used to make CMA. The optimum asphalt contents for control mix and for six different petroleum contaminate soils were selected. The Marshall stability tests indicated that the CMA with PCS is strong enough to be used in low volume roads, i. e., a Marshall stability, values higher than 500 lbs. The durability of CMA made with PCS seems to be adequate. The average hydraulic conductivity of control mix and CMA with PCSs were low.

For future research, document will be produced to show the leaching test results. Then a cost benefit analysis will be performed to design a medium size cold mix asphalt plant that can process 50 tons of soils a day.

APPENDIX A

Tables

Table 1 Data on Six Contaminated Soils from NJ

soil Type						
	PCS # 1	PCS # 2	PCS #3	PCS # 4	PCS # 5	PCS # 6
Soil Classification	Well graded	Clay silt	Silty sand	Poorly graded	Silty clay	Poorly graded Sand with Silt
In-Situ Moisture Content (%)	7.3	14.3	24.4	14.4	19.6	10.1
Level of Contamination	0.11% Heating oil	0.12% Heating oil	0.66% Heating oil	25 ppm Gasoline	1500 ppm Gasoline	330 ppm Gasoline

Table 2 Grain Size Distribution of PCSs

	Percent Retained					
Sieve	PCS #1	PCS #2	PCS #3	PCS #4	PCS #5	PCS #6
3/4	0.0	0.0	0.0	0.0	0.0	2.2
3/8”	0.0	0.0	0.0	0.0	0.0	5.0
US #4	5.0	12.0	0.0	2.0	5.0	5.9
US #10	5.0	7.0	3.0	6.0	10.0	3.0
US #40	52.0	9.0	22.0	42.0	20.0	12.8
US #100	20.0	6.0	54.0	50.0	11.0	58.7
US #200	13.0	3.0	5.0	0.0	9.0	7.3
Finer than #200	5.0	63.0	16.0	0.0	45.0	5.1

Table 3 Design grain size distribution of aggregate and PCSs

	Control	PCS #1	PCS #2	PCS #3	PCS #4	PCS #5	PCS #6
1“ Size 1/2“	252	276	264	264	252	252	270
1/2“ Size 1/4“	288	312	264	264	288	288	300
1/4“ Size 1/8“	192	156	156	144	192	144	120
1/8“ Size #10	108	84	96	72	108	72	72
Dust US #10	180	0	105	216	180	102	258
Sand US #10	180	0	210	0	0	240	0
PCS US #10	0	372	105	240	180	102	180

unit: gram

Table 4a Marshall Stability Test Results: Control Mix

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	136.03	16.78	407.6	6.00	25.14
4.5	140.70	13.26	342.5	8.50	23.09
5.0	138.53	13.95	616.4	18.00	24.67
5.5	136.86	13.97	1690	23.66	25.98
6.0	137.70	12.75	1172	21.56	25.92

Table 4b Marshall Stability Test Results: Soil #1

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	138.60	15.23	420.2	13.75	23.85
4.5	134.66	16.99	484.2	12.33	26.00
5.0	139.10	13.58	343.3	13.33	24.36
5.5	137.80	13.35	369.2	26.00	25.45
6.0	137.44	12.93	366.0	29.00	26.05

Table 4c Marshall Stability Test Results: Soil #2

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	138.74	15.12	1185.16	8.66	23.77
4.5	137.50	15.36	1073.33	5.00	24.86
5.0	137.70	14.46	619.00	11.33	25.12
5.5	137.90	13.28	810.00	8.33	25.40
6.0	136.00	14.17	422.33	16.00	26.82

Table 4d Marshall Stability Test Results: Soil #3

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	136.86	15.64	1417.30	5.33	25.14
4.5	133.34	17.19	1058.80	6.00	27.50
5.0	136.03	14.50	1329.83	7.66	26.43
5.5	134.16	15.30	1019.66	9.00	27.44
6.0	135.53	15.06	471.70	12.66	28.50

Table 4e Marshall Stability Test Results: Soil #4

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
3.5	139.15	15.53	320.17	14.00	23.24
4.0	134.08	17.99	405.33	10.66	26.33
4.5	135.62	15.25	322.50	14.00	25.87
5.0	136.86	14.99	848.00	20.66	25.58
5.5	131.45	14.77	693.00	19.00	26.98

Table 4f Marshall Stability Test Results: Soil #5

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	136.24	16.67	706.00	14.00	25.14
4.5	135.62	16.40	620.93	15.66	25.87
5.0	137.50	14.60	576.60	12.66	26.00
5.5	135.40	14.77	241.20	19.33	26.64
6.0	136.00	14.17	76.20	8.33	26.82

Table 4g Marshall Stability Test Results: Soil #6

AC (%)	Unit Wt. psi	Total Void (%)	Marshall str. lb	Flow 100 in	VMA (%)
4.0	138.53	15.27	216.0	8.00	23.88
4.5	137.90	15.00	449.5	16.33	24.62
5.0	132.70	17.38	428.0	10.66	27.84
5.5	135.62	14.77	520.0	10.00	26.65
6.0	137.70	13.12	582.6	24.00	25.92

Table 5 Optimum Properties of Asphalt concrete with PCSs

Asphalt concrete Properties	Control	Soil # 1	Soil # 2	Soil # 3	Soil # 4	Soil #5	Soil # 6
Strength (lbs.)	1400	475	900	1200	700	590	550
Flow (100 in)	18	17	10	8	17	13	20
Air Voids (%)	13	12	14	15	15	15	14
VMA (%)	24.75	25	25.5	26.75	26	26	26.5
Density (psi)	137	138.5	138	136	136	37.5	135
Optimum Asphalt Content (%)	5.5	5.25	5.5	5.75	5.25	5	5.75

Table 6 Durability: Wet-Dry Test

CMA MIX	TSR %	% Swell
Control	100	1.06
CMA with Soil #1	90.2	2.09
CMA with Soil #2	100	1.91
CMA with Soil #3	100	1.926
CMA with Soil #4	100	5.8
CMA with Soil #5	28	2.71
CMA with Soil #6	85.7	.32

Table 7 Durability: Freeze-Thaw Test

CMA MIX	TSR %	% Swell
Control	82	11
CMA with Soil #1	100	2.4
CMA with Soil #2	100	2.3
CMA with Soil #3	100	2.3
CMA with Soil #4	83.6	2.2
CMA with Soil #5	49.9	4.8
CMA with Soil #6	50.3	5.7

Table 8 Hydraulic Conductivity values of CMA concrete made with PCSs and the control

CMA Mix	Average hydraulic conductivity (cm/sec)
Soils type	Specimen
Control	7.5 E -5
PCS #1	7.0 E -5
PCS #2	4.6 E -5
PCS #3	3.2 E -5
PCS #4	1.0 E -5
PCS #5	1.0 E -5
PCS #6	1.0 E -5

APPENDIX B

Figures

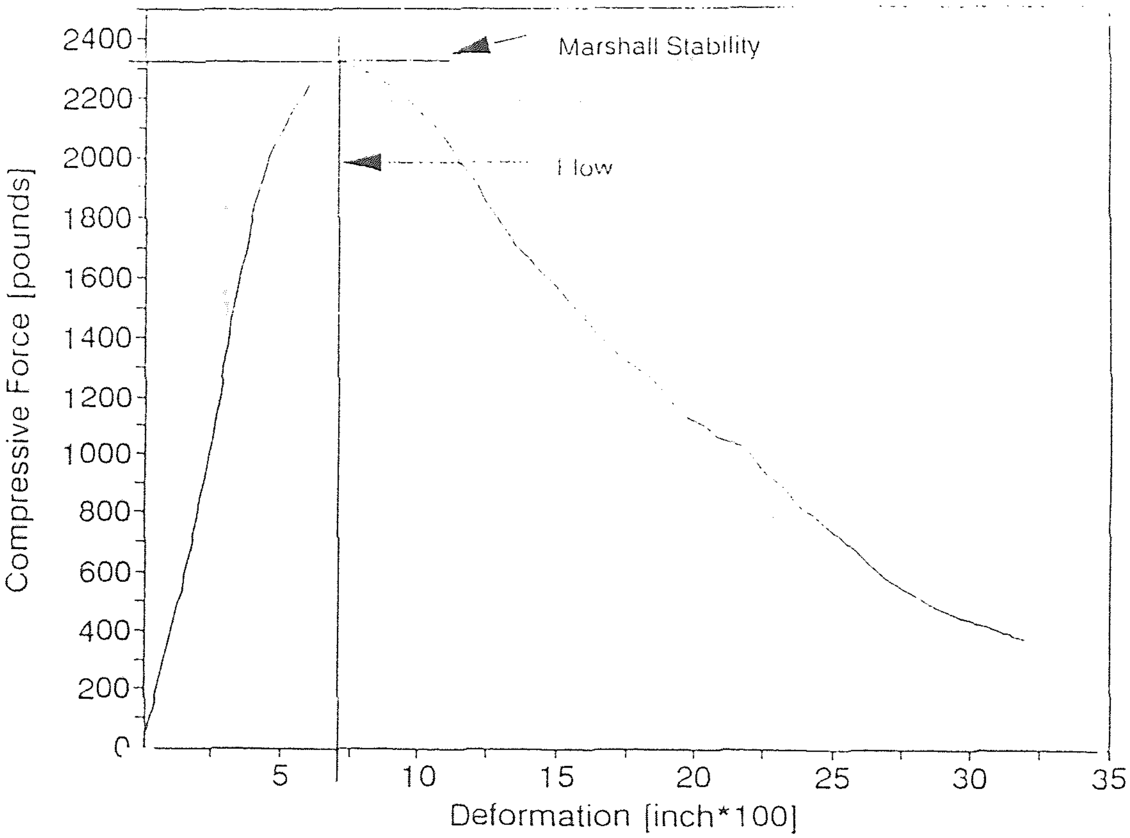

Figure 1. A Typical Marshall Test Result

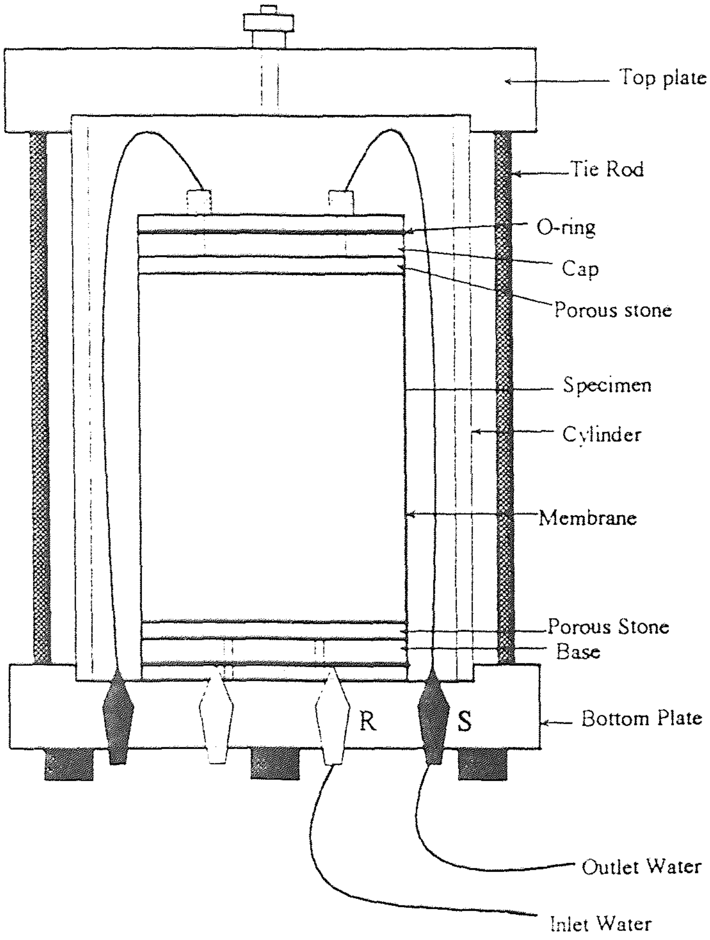

Figure 2 Permeameter chamber cell

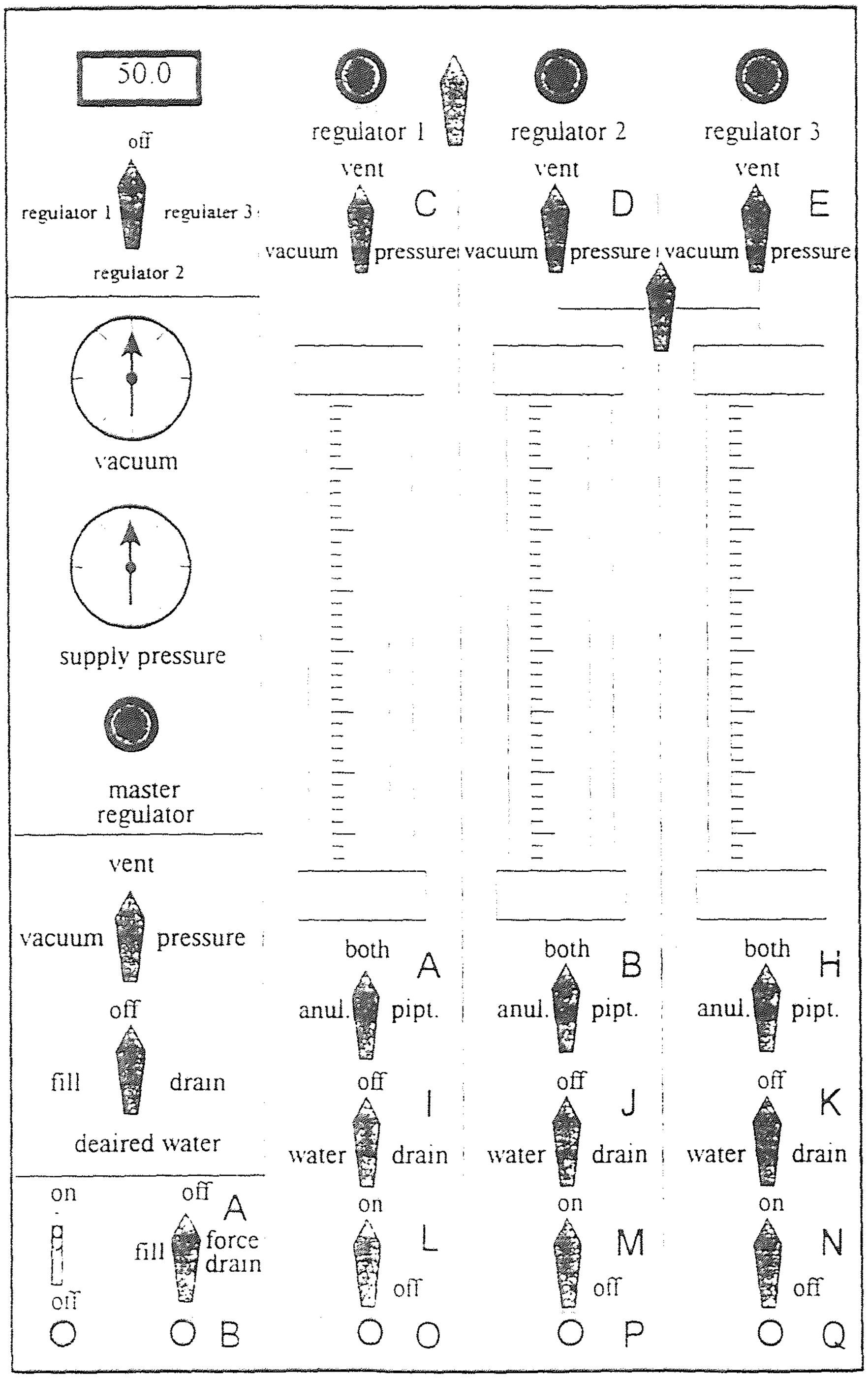

Figure 3 Brainard-Kilman control panel

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