CREATING A PERFORMANCE-BASED ASPHALT MIX

DESIGN TO INCORPORATE UINTA

BASIN OIL SANDS

by

Michael C. Vrtis

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STATEMENT OF THESIS APPROVAL

The thesis of   **Michael C Vrtis**

has been approved by the following supervisory committee members:

| **Pedro Romero** | , Chair | **10/26/2012** |
| | | Date Approved |

| **Andy Hong** | , Member | **10/26/2012** |
| | | Date Approved |

| **Amanda Bordelon** | , Member | **10/26/2012** |
| | | Date Approved |

and by   **Chris Pantelides**   , Chair of

the Department of   **Civil and Environmental Engineering**

and by Donna M. White, Interim Dean of The Graduate School.

ABSTRACT

       This research was an effort to create and test a performance-based mix design that allows for oil sand to be incorporated as the binder material. The design is based on creating an open-graded aggregate blend that will allow incorporating the optimum volume of oil sand.

       The oil sand used in this project is a natural, unmodified material that was characterized to explore its unique attributes. Aggregate stockpiles were blended to find the maximum space for the oil sand to be added in the mix. A field project was performed to bring the laboratory mix to full-size scale. Even though there were some minor delays while trying to incorporate the oil sand into the mixing chain, the results prove that the design from this work was feasible. Loose mix samples were obtained and brought back to the laboratory for testing.

       The Hamburg Wheel Tracking Device (HWTD), Bending Beam Rheometer (BBR), and Asphalt Mixture Performance Tester (AMPT) were performed on the loose mix samples from the field project. The results were compared with the laboratory mix results as well as with results from conventional hot mix asphalt (HMA) mixes used in Utah. The HWTD shows the mix has a solid aggregate structure; however, there is a potential for premature pavement failure due to moisture susceptibility. In the BBR, all of the oil sand mixes had a

greater creep stiffness at low temperatures than conventional binder grades; meaning that the oil sand mixtures are more likely to crack at low in-service temperatures when compared to the performance binders typically used in interstate roads. In the AMPT, at high in-service temperatures, the dynamic modulus was lower than the conventional mixes, meaning there is a greater likelihood of rutting occurring at high temperatures because the binding material is softer.

Based on these performance measures, it was determined that it is possible to develop a mixture that incorporates oil sands into a pavement material for rural or low volume roads. There are economic and environmental advantages to using oil sand mixes as a roadway material. Oil sand mixes require a lower mixing temperature than HMA and, therefore, can save on both fuel costs and emissions.

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INTRODUCTION

Problem Statement

Materials that are conventionally utilized in road construction are costly and energy demanding. Specifically, asphalt binder is a petroleum derivative; forcing its cost and availability to be dependent on the constantly-fluctuating supply and demand of the petroleum industry. Having the ability to incorporate alternate material sources into pavements would be of great benefit to the industry. One alternative product that can be used to reduce the dependency on the petroleum-based asphalt is oil sand. Oil sand is a natural material that is available in Uinta County, Utah. Even though for many years Uintah County oil sand has been available, in general, it is still an underutilized resource. One of the reasons it has been underutilized is that there is no specification or standard methodology to incorporate oil sand into road material. Having a methodology that uses the latest mix design procedures and incorporates naturally occurring oil sand would be beneficial.

The goal of this project is to develop an asphalt pavement mix design procedure that will allow new materials to be incorporated into the mix. Specifically, using a performance-based approach, natural Uintah County oil sand will be used to replace the petroleum binder that is used in conventional hot mix asphalt. Such a product would help overcome some of the difficulties associated with asphalt binders.

Objectives

This project has three primary objectives:

1. To develop an appropriate methodology to incorporate oil sands as a road material.

2. To evaluate the potential performance of this mixture using available laboratory tests. The Hamburg Wheel Tracking Device (HWTD), Bending Beam Rheometer (BBR), and Asphalt Mixture Performance Tester (AMPT) were utilized in the laboratory for this purpose.

3. To evaluate the feasibility of this project by conducting a field trial.

Approach

The objectives of this work will be met by using mixture volumetric relations to develop a mix design that incorporates the maximum amount of oil sand. Using mechanical testing, the potential performance of the mix will be evaluated. Figure 1 shows a flow chart that summarizes the steps followed in this work. The volumetric design consisted in finding the aggregate stockpile blend that would allow for the maximum voids in the aggregate. Given that the oil sand will be used to fill these voids, the blend with the maximum voids will allow for the most oil sand to be used, providing the most bitumen to the mix.

With the oil sand being centralized in Uintah County, there is an added constraint that only local Uintah County materials be used in this project.

The first step of this project consisted of characterizing the gradation and volumetric properties of the aggregate available. Once the proper aggregate gradation blend was determined, the next step was to characterize the oil sand. The oil sand source was identified and an oil content of the oil sands was found by both burn-off and chemical extraction methods. The oil sand temperature properties were explored to determine an ideal mixing temperature. The ideal mixing temperature is a temperature hot enough to transfer oil to the aggregates, but not too hot to cause the oil sand to emit smoke. The effect of the mixing temperature on the cold weather behavior was also considered when selecting the optimum mixing temperature.

With the optimum mixing temperature, laboratory volumetric verification was performed to ensure the mix design had the desired volumetric properties. Following the volumetric analysis, performance testing was done using the Hamburg Wheel Tracking Device (HWTD). This device was used to simulate traffic loading and evaluate the moisture susceptibility of the pavement mix. The results of all laboratory work were used to develop the Plant Mix Oil Sand Asphalt (PMOSA) Specification. The PMOSA Specification guides the engineer to create an asphalt mix incorporating oil sand as the binder, then requires performance testing similar to the testing done in this project to verify the mix's performance capabilities.

The PMOSA mix design was then taken to the field to bring the design to full scale. The field project was done to find potential issues that may occur when trying to scale up the design from the small scale laboratory work used to develop the design. The PMOSA Specification allows for a range in the percent of oil sand used. The field project used two different proportioned mixes at both ends of the oil sand content range.

Loose mix samples were taken from each mix and brought back to the University of Utah to perform laboratory tests.   Samples were made for the Bending Beam Rheometer (BBR), the Asphalt Mixture Performance Tester (AMPT), and the Hamburg Wheel Tracking Device (HWTD). The BBR was used to determine the mix's cracking potential at low temperatures. The AMPT was used to find the mix's stiffness characteristics at high temperatures. The field project results were then compared to the laboratory results and adjustments were made to the PMOSA Specification in preparation for the 2012 construction season.

Background

Oil sand is a naturally occurring petroleum deposit consisting of sand, clay, water, and a form of petroleum called bitumen.   In the United States, bitumen is more commonly known as asphalt binder because it is used as the binding medium in asphalt concrete. Asphalt binder or bitumen is a thick crude oil that must be heated in order to flow.

Major oil sand deposits are located throughout the world; however, the largest deposits are located in North America and Eurasia. Each oil sand deposit has unique surrounding environmental and geographical characteristics such as depth, terrain, temperature, and location relative to other resources. These geographical and environmental constraints limit the mining and use of oil sand.

The world's largest oil sand deposit is located in the Athabasca region of Alberta, Canada. Currently, oil sand is mined and petroleum crude is extracted from the oil sand on a large commercial scale in northern Alberta. As of 2008, the Athabasca region

produced 1.5 million barrels per day (MMBPD) and is expected to produce 3.3 MMBPD by 2028 [1]. Deposits in this region are near the surface and are in relatively level terrain making them easily accessible. Oil sands, historically, have been mined simply with a shovel-bucket and large mining truck, however, an insitu extraction process is used to reach more deposits. The extraction methods employed in the Athabasca region require massive amounts of resources and energy [2].

The largest oil sand deposits in the United States are in eastern and southeastern Utah. Figure 2 shows the deposit locations within the state. There are six major deposits in the Uinta Basin. Other major deposits are located in the San Rafael Swell, the Circle Cliffs, and the Paradox Basin. The oil sand used for this research is from the Crown Energy's Asphalt Ridge deposit in the Uinta Basin, Figure 3. Uinta Basin oil sand was formed during the Cenozoic Era, around 34 – 56 million years ago. [2]

It has been found to be economically challenging to commercially extract crude oil from Utah oil sand because of the chemical composition, deposit size, and the remote locations of the deposits. In comparison to the Athabasca oil sand deposits, the Utah deposits are much smaller and less uniform. The Athabasca deposit is an estimated 100 times larger than all of the Utah deposits combined. (Athabasca deposit has $1.7*10^{12}$ barrels of original oil in place. All of the Utah deposits combined are estimated to have $1.2*10^{10}$ barrels of original oil in place [1]). Small and inconsistent deposits deter the large initial investment required to build an onsite extraction facility. The remote locations in dry mountainous terrain make the deposits more difficult to access. Another primary issue stopping the commercial extraction in Utah is the lack of a water source for

the extraction process. The Athabasca River supplies the necessary water for extraction at the Canadian deposits [2].

Over the last 30 years, there have been numerous attempts for extraction and crude oil production in Uintah County but most have been scrapped due to the previously mentioned challenges and the low cost of regular crude oil production. There are currently only small scale pilot extraction projects taking place at Temple Mountain and Asphalt Ridge in Uintah County [2].

The first recorded use of oil sand as a pavement material was done by Sidney Wells of the Canadian Federal Department of Mines in 1913. The project was dropped because of the relative cost; however, two roads were paved in downtown Edmonton using oil sand. In Uintah County, oil sand from Asphalt Ridge has been used as a road material for over a century [1]. Pavement material is made from oil sands by mixing coarse aggregates with the oil sand in either a hot or cold mixing process. Some mixes add a small amount of conventional asphalt binder in an effort to stiffen the pavement. There is currently a patent for mixing oil sand with conventional asphalt binder and aggregates in a hot mix plant process held by Ned B. Mitchell [4]. This research is the first attempt to use modern mix design tools to address oil sand pavements.
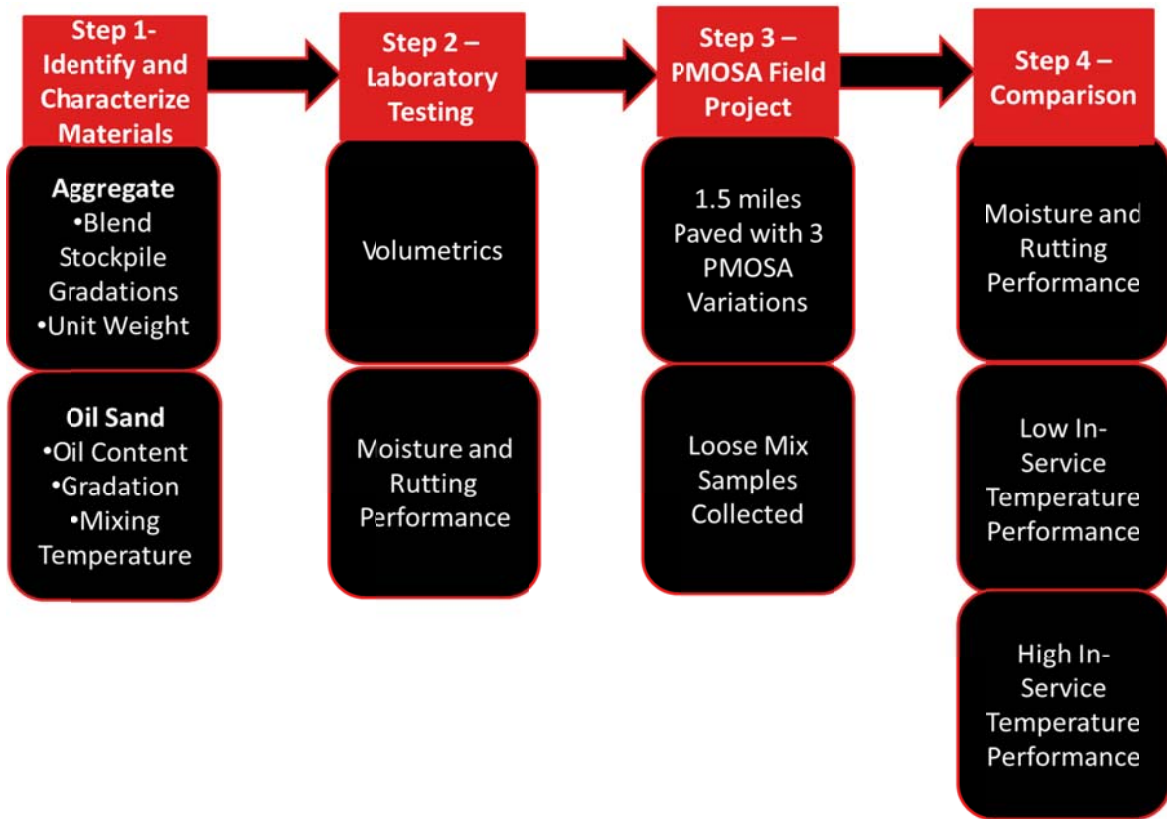
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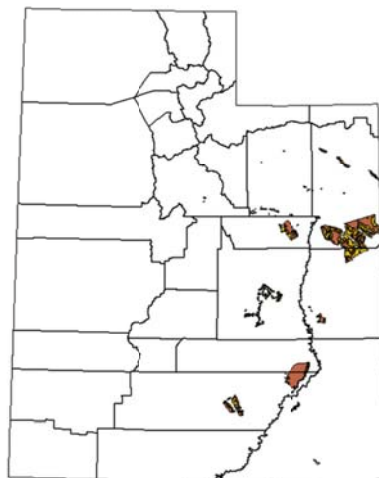
Figure 2- Oil Sand Deposits in Utah [3]

Figure 3- Asphalt Ridge Deposit, Uintah County, UT

LITERATURE REVIEW

Economics

In order for oil sand pavements to be used instead of conventional asphalt, oil sand pavements must be economically advantageous, while still meeting a minimum performance level. The economic advantages of oil sand pavements decrease the further the oil sand needs to be transported away from the mine. The cost increases due to the transportation distance because sand is a resource that is readily available in most areas. Within the oil sand material, the sand is already mixed with the binder; therefore, when transporting the binder there is also the additional cost of transporting 90% sand with the oil. Uintah County is home to several oil sand mines; consequently the economic benefit will be maximized for projects in the county.

Prior to the commencement of this research, an economic analysis was performed by Utah Science, Technology and Research Initiative (USTAR). The resulting report, "*Economic Feasibility of Oil Sand Use in Asphalt Pavements,*" compares the cost of hot mix asphalt paving processes already in place to the cost of incorporating oil sands and creating a new mixing process [4]. Using the assumption that production rates will ramp to full capacity in five years, the conclusion was made that "An overall favorable economic result for private industry, as well as, both local and state governments is predicted." [4] The oil sand mix design utilized in the economic analysis performed by

USTAR contained 1% conventional asphalt binder in addition to the oil sand. The oil sand mix developed through this project did not use any conventional asphalt binder, thus, further reducing costs projected by the USTAR report.

Another advantage of oil sand pavements is the lower mixing temperature. Hot mix asphalt is normally mixed at around 177° C (350° F). The optimum mixing temperature for oil sand mixes was determined by this project to be 104° C (220° F). There is a substantial reduction in energy required to heat and place the pavement, thus, saving money spent on fuel for heating. A lower mix temperature creates a more environmentally friendly pavement by lowering the emissions generated and helping to maintain Uintah County air quality.

Theory of Asphalt Mix Design

Asphalt roads make up over 94% of the paved roads and highways in the United States [5]. Asphalt concrete pavements are utilized rather than Portland cement concrete pavements because of the cost, construction speed, ride quality, and recyclability. A well-designed asphalt pavement will be able to carry the traffic loads for the duration of its design life. A pavement surface must provide adequate friction to the tires of the vehicle. The pavement should also be able to resist irregularities that develop as a result of traffic loading such as rutting, stripping, or potholing.

Throughout the last half-century there has been an increased federal effort to provide roads with the desirable characteristics mentioned previously. In 1987, Congress appropriated funds to begin the Strategic Highway Research Program (SHRP). SHRP was initiated to address pavement life, maintenance, and premature pavement failures [6].

The Superior Performing Asphalt Pavements, or Superpave, mix design method was developed during SHRP. Another important contribution to the asphalt industry that resulted from SHRP, was the paradigm shift from designing mixes based on empirical experience as done for almost a century, to incorporating mechanical analysis into the mix design. A mechanistic-based mix design process creates a mix that is tailored to perform well in its given environment and application instead of the recipe-like mix designs used previously. This performance-based approach provided the basis for this research aimed at incorporating new materials into asphalt pavements.

As a part of this paradigm shift, the rating and nomenclature of asphalt binders was changed to incorporate its optimal performance temperature range. Under the Performance Graded (PG) rating system, the binders are named for their maximum and minimum pavement design temperatures. For example, PG 64-28, a binder utilized in Utah, is designed to be stiff enough to withstand repeated loading at a high temperature of 64° C (147° F) and soft enough not to crack at a temperature above -28° C (-18° F) [6]. In an asphalt pavement, the aggregate structure is responsible for transferring the traffic loads into the sublayer. The Superpave method utilizes a dense-graded aggregate gradation. In a dense-graded gradation, the left image in Figure 4, aggregates from all sieve sizes are used almost equally.

Within a dense-gradation the small and intermediate-size aggregates act more as a filler medium than a structural component. The purpose of these filler-size aggregates is to help reduce total binder content and binder drain-down; however, since their contribution to the load transfer is minimal, in theory, they can be removed from the mix without compromising the structural performance of the pavement. This concept has led

to the development of alternatives to dense-graded mixtures. A gapped-gradation, the right image in Figure 4, means there is a relatively small amount of intermediate size aggregates in the gradation and allows for the voids between large aggregates to be filled with fine aggregates and binder. Gap-graded mixtures rely on the coarse aggregate skeleton to transfer the traffic load into the sub-layers. The coarse aggregate structure is responsible for rutting resistance; the bitumen binder is responsible for holding the aggregate structure together. Based off this concept, Gap-Graded Hot Mix Asphalt (GGHMA) was developed to take full advantage of large aggregate-on-aggregate interaction. GGHMA has been used in Europe for over 30 years because of its durability and rut resistance [3]. Figure 5 shows the hypothetical load transfer path through dense and gap-graded gradations.

The paradigm shift created by SHRP is imperative for this project because it is a transition from a prescriptive recipe towards a performance-based design. A performance-based approach to developing mix designs allows for innovations like GGHMA to be used when they are deemed necessary. GGHMA has an ideal aggregate structure to use with oil sands as the binder because the void spaces between the large aggregates provide space to be filled with the large amount of fine aggregates within the oil sand. This concept will be addressed in more detail in Laboratory Procedures and Results.

Mechanical Testing

The purpose of conducting mechanical tests in the laboratory is to help characterize how the pavement material will respond to traffic loading and environmental

conditions in the field. The tests are used as a screening tool since mixes that do poorly

on the laboratory tests are likely to suffer from premature failure if placed on the field.

Three different laboratory tests (HWTD, BBR, and AMPT) were used to evaluate the

failure potential in the field applications.

Hamburg Wheel Tracking Device

The Hamburg Wheel Tracking Device (HWTD) is used to obtain rutting potential

and moisture susceptibility at a high in-service temperature. The HWTD repeatedly rolls

a weighted steel wheel across the surface of an asphalt concrete slab that is immersed in a

warm temperature water bath, commonly 50° C (122°F). The HWTD, Figure 6, can

simultaneously test two asphalt slabs that have a length of 320 mm, a width of 260 mm,

and a thickness of 50 mm. The test results are reported as either pass or fail based on

whether the mix can withstand 20,000 wheel passes with less than 20 mm of rutting [8].

Individual states have adopted various combinations of bath temperature, total number of

wheel passes, and maximum allowable rutting depth to fit their individual needs. For

example, in 2006, the Texas Department of Transportation issued a technical advisory

stating that a passing mix must have less than 12.5 mm of rut depth after 10,000, 15,000,

or 20,000 wheel passes for binder grades PG 64-xx, PG 70-xx, and PG 76-xx,

respectively [9]. In Utah, the bath temperature is changed for each binder grade.

According to UDOT MOI 990, the bath temperature should be 46° C, 50° C, and 54° C

for PG-58-xx, PG-64-xx, and PG-70-xx, respectively [10].

The HWTD slabs are compacted using a linear kneading compactor at the

designated compaction temperature. In the linear kneading compactor, the mix is placed

into a heated steel mold that is 320 mm x 260 mm. Twelve and a half millimeter (12.5 mm) steel plates are placed perpendicular over the mix inside the mold. The linear kneading compactor then repeatedly moves the mold under a steel roller that is slowly lowered by a manual hydraulic jack. The drum presses down over the plates and an even compaction on the slab occurs. Once the target height is reached the compactor is stopped. The roller is lowered to a calculated height that will produce the desired density in the slab. It is important that the slabs meet the target air voids to ensure that the laboratory samples being tested match the level of compaction used in the field.

After the slab has been properly prepared, it is placed into the HWTD water bath. The sample is allowed 30 minutes to soak in the bath in order to ensure the slab has uniformly reached the target testing temperature. Each steel wheel has a diameter of 203.5 mm and a width of 47.0 mm. The load is fixed at 685 N and the average contact stress is 0.73 Mega Pascals (MPa). The manufacturer states that a contact stress of 0.73 MPa approximates the stress produced by one rear tire of a double-axle truck [8]. On average, the HWTD runs 53 ± 2 wheel passes per minute; a full test of 20,000 passes takes about 6.5 hours to complete.

Bending Beam Rheometer

The Bending Beam Rheometer (BBR), Figure 7, is utilized to measure properties at cold temperatures. The material behavior at cold temperatures is a critical piece of information for asphalt mix designs because the binder stiffens as the temperature decreases, thus cracking can occur during the winter due to cold temperatures. The BBR applies a small load (2000-4000 mN) to a quarter inch thick specimen in a cold liquid

alcohol bath for 4 minutes. As the load is applied, the machine measures deformation at the center of the beam in order to estimate creep stiffness and bending characteristics at the desired temperature. A sample results page generated by the BBR can be seen in Appendix C; the estimated creep stiffness after the load has been applied for 1 minute is reported in Mega-Pascals (MPa).

The BBR has a simple three point bending setup. The supports are 100 mm (4") apart with the load being applied directly between the supports at 50 mm (2") away from either support. Figure 8 shows the three point bending set-up, the picture was taken outside of the liquid bath for clarity.

The BBR was originally designed to test asphalt binders only. Hot liquid binder was poured into a mold that is 6.75 mm (1/4") thick, 12.5 mm (1/2") wide, and 125 mm (5") long. Since the BBR was originally developed, research was done to expand the capabilities to test complete asphalt pavement mixes instead of binder only samples [8]. In order to test the cold temperature properties of the asphalt mixtures, a sample must be mixed and compacted into a 150 mm (6") diameter puck according to the normal mixing and compaction procedure for that mix design. The puck is then cut down into 6.75 mm by 12.5 mm by 125 mm BBR specimens. Careful attention must be paid during cutting to ensure uniformity of the specimens and that the specimens will be loaded in the BBR in the same direction that they were compacted.

Asphalt Mixture Performance Tester

The Asphalt Mixture Performance Tester (AMPT), Figure 9, is a new device that is just emerging into the asphalt industry. There are only a limited number of AMPTs

available within the United States; fortunately for this research, the Utah Department of Transportation (UDOT) owns several of them and has been a leader in implementing and building data sets. The concept behind the AMPT is to test an asphalt mix at a series of temperatures and loading rates to develop a master curve of the dynamic modulus for the mix. In other words, the dynamic modulus is the stiffness of the mix as it changes with loading time and temperature. The standard testing temperatures are 4° C, 20° C, and 40° C. The standard loading rates at each temperature is 0.01 Hz, 0.1 Hz, 1 Hz, and 10 Hz. The dynamic modulus master curve can then be used to predict the characteristics of the pavement at any given combination of temperature and loading rate.

An AMPT sample is mixed and compacted in a gyratory compactor according to the normal procedure used for that mix. The 170 mm tall compacted 150 mm diameter is then cored to a diameter of 100 mm and cut down to a height of 150 mm. Both ends of the cylinder need to be cut so all surfaces are smooth cut. Two rows of three evenly spaced studs are then epoxy adhered to the core. The studs are spaced 120° apart from one another with a distance of 50 mm between the top and bottom row bolts, Figure 10. After the epoxy has fully cured, the sample is ready to be placed into the temperature incubator in preparation for the AMPT testing.

A sample is ready to be tested in the AMPT after it has been allowed to uniformly reach the desired testing temperature. Three linear variable differential transformers (LVDTs) are placed between the top and bottom studs to measure strain as the loads are applied. Once the sample has been placed into the AMPT and the LVDTs are connected, the chamber is closed and the testing begins once the chamber reaches the testing temperature.

The purpose of using the AMPT for this project is to compare the high in-service temperature characteristics of the oil sand mix to the large AMPT result database maintained by UDOT. This comparison to other asphalt mixes helped determine what environments the oil sand mix could successfully be put in place.
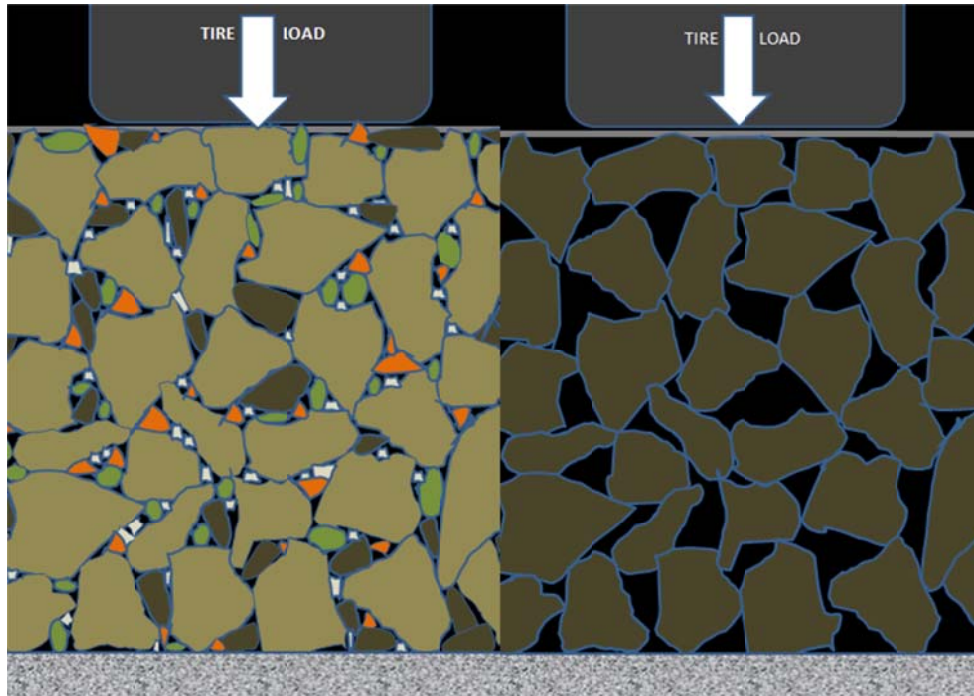
Figure 4– Schematic of Dense-Graded and Gap-Graded
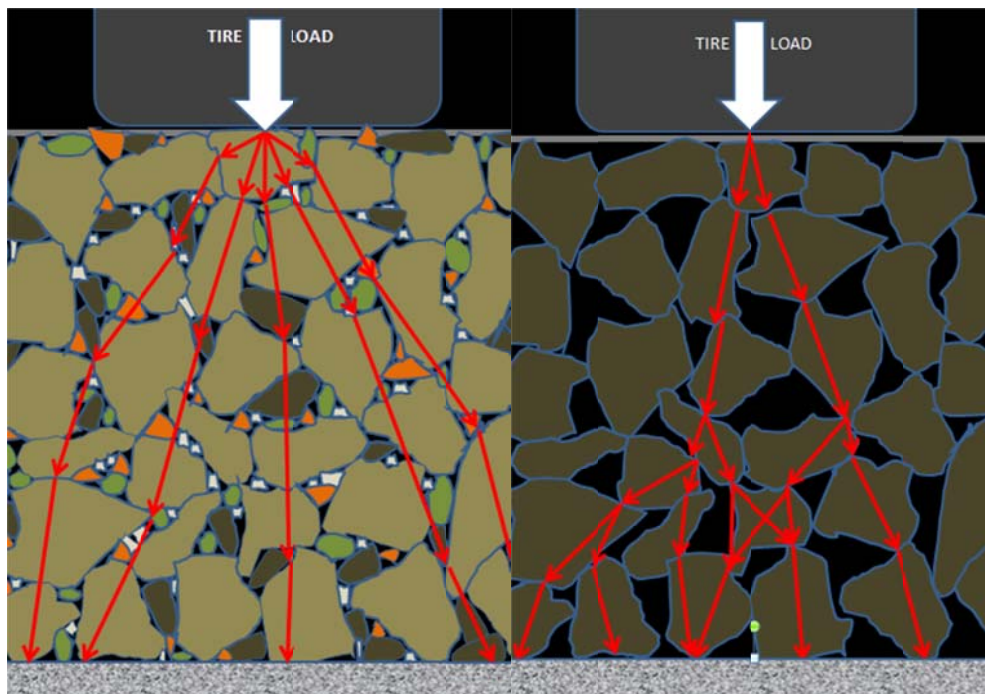
Figure 5- Schematic of Load Transfer within the Asphalt Mix

Figure 6- Hamburg Wheel Tracking Device

Figure 7- Bending Beam Rheometer

Figure 8- BBR Loading Set-Up (Outside of Liquid Bath)

Figure 9- Asphalt Mixture Performance Tester

Figure 10- AMPT Testing Specimen

LABORATORY PROCEDURES AND RESULTS

As outlined in the introduction, the steps required to build a mix design incorporating oil sand in the laboratory were: oil sand analysis, aggregate analysis, combined aggregate and oil sand volumetric analysis, and the performance testing.

Oil Sand Analysis

Prior to developing a mix design, it was necessary to explore the unconventional properties that the oil sand would be adding to the mix. The properties that needed to be determined were oil content, gradation, and optimum mixing temperature.

Oil Content and Gradation

The oil sand utilized during this research was obtained from Crown Energy's Asphalt Ridge deposit. It was essential that Crown Energy provide the oil sand from the richest portion (highest oil content) of the mine, thus maximizing the amount of binder in the oil sand pavement. Once a large amount of oil sand was obtained from the mine, characterization of the material began by finding the oil content in the oil sand. Oil content was determined by using both the burn-off method (AASHTO T 308) as well as a chemical extraction method (AASHTO T 164) done by an independent laboratory, Garco

Testing Laboratories (Appendix B). The representative oil content of the oil sand used in this research was found to be 12.97% oil by mass of the oil sand.

Following the burn-off of the oil, the gradation of the remaining sand was determined, Figure 11. The sand had a fine-graded size distribution, with all of the material passing a 2.36 mm screen (#8 screen). The large amount of fine material from the oil sand presented significant challenges when combining with aggregates; this will be discussed in more detail in later sections.

Mixing Temperature

In an effort to investigate the consequences of heating the material as it is done in the hot mix plant, the effect of holding the materials at high temperatures for extended periods of time was investigated. Samples of approximately 50 g were heated for 7 hours at a constant temperature. The change in mass was recorded. Figure 12 shows a plot of the percent loss verses time for each temperature. In general, it can be seen in this plot that the mass-loss increases at higher temperatures. The greatest mass-loss occurred when heated to 127° C (260° F). It was found from the mixing process that the oil sand must be heated above 104° C (220° F) for maximum coating and oil transfer from the sand to the aggregates. During the process, it was observed that at temperatures above 121° C (250° F) the material begins to smoke and emits a distinct musky oil smell, indicating the oil sand is being overheated. Light end oil components are believed to be lost when the material is overheated. There were no signs of overheating visible at 104° C (220° F); therefore the optimum mixing temperature was recommended to be between 104° C and 116° C.

In an attempt to measure the mechanical properties of the oil sand that were lost due to overheating, the BBR was used to estimate the creep stiffness at cold temperatures of the overheated samples. This was done by heating a sample to the specified temperature for 7 hours and then compacting the sample in a gyratory compactor at the same specified temperature. For example, a 3,000 g sample of oil sand was placed in the oven for 7 hours at 104° C (220° F). The gyratory compactor mold was also heated to 104° C; after 7 hours, the oil sand was compacted with 75 gyrations into a 150 mm (6") diameter cylindrical puck. Samples were prepared in this manner for each target temperature. The 150 mm diameter pucks were then cut into small 6.75 mm (¼") thick by 12.5 mm (½") wide by 125 mm (5") specimens for testing in the BBR (AASHTO T313).

A plot of the BBR results can be seen in Figure 13. The creep stiffness of the compacted oil sands peaks at 104° C (220° F). The lower creep stiffness at the 127° C (260° F) confirms that there is a detrimental change in mechanical properties when the oil sand is overheated and emits smoke. As stated earlier, it was found from the mixing process that the oil would not transfer to the aggregates below 104° C. Also no signs of overheating (odor and smoke) could be observed when mixing at 116° C. The BBR results reaffirmed that the optimal mixing temperature range is 104° C to 116° C.

Aggregate Analysis and Volumetrics

Developing a working mix design began by obtaining aggregates from Uinta Basin. The aggregates were obtained from the Burdick Maser East Pit and the stockpile

gradations were provided by Burdick, Figure 14.   The gradation of the oil sand is also plotted in Figure 14 to show the drastic differences in the gradations.

Aggregates from the 19 mm (¾"), 12.5 mm (½"), and 4.75 mm (#4) stockpiles were shaken down to individual sieve sizes and washed (AASHTO T30 and AASHTO T27-99). Different stockpile blends were created to find the aggregate structure that allowed the most room for oil sand in the mix. This was done by finding the percentage of air voids in different aggregate blends (ASTM C127 and ASTM C29). Table 1 shows the complete unit weight results for the trials.

The individual gradations of the blends can be seen in Figure 15. The 4.75 mm (#4) stockpile was not used in the design because the oil sand was already contributing a large amount of fine aggregates to the mix.

The total gradation after adding 40% oil sand (by total weight of the mix) was then plotted to make the final determination of the best aggregate stockpile blend, Figure 16. The composite gradations were then compared to typical gradations for dense-graded and GGHMA asphalt mixes, shown previously in the Literature Review, Theory of Asphalt Mix Design. It should be noted that due to the large amount of fine aggregates within the oil sand none of the gradations closely matched typical gradations, although, gradations 2A and 2B most closely fit the typical gradations.

Blend 2A was selected for use in the mix design because it had a lower unit weight than Blend 2B. With the coarse aggregate used in this project, the lower unit weight is beneficial because it creates more voids in the coarse aggregate (VCA); a higher percent VCA allows more room for oil sand to be added thus putting more bitumen into the mix.

The VCA is shown conceptually in Figure 17. The solid particles represent the coarse aggregate structure of the GGHMA mix on the left side of the figure and then are compressed on the right side of the figure to show the available VCA. The VCA is shown in the left side of the figure as the spaces between the solid particles and then shown as the volume filled with air and oil sand on the right side of the figure.

Due to the 40% VCA found from the unit weight analysis, the coarse aggregate blend 2A (75% 19 mm and 25% 12.5 mm blend) would take up 60% of the total volume of the mix. The remaining 40% is then occupied by oil sand, air voids, and a small amount of hydrated lime (hydrated lime, not shown in Figure 17, fills the remaining 0.5% volume within the VCA). This process can be seen in the equations from blend 2A.

$$G_{SB} = \frac{\gamma_{DR}}{\gamma_W} = \frac{1558.5 \frac{kg}{m^3}}{1000 \frac{kg}{m^3}} = 1.56$$

$$VCA = 1 - \left(\frac{G_{SB}}{G_S}\right) * 100 = 1 - \left(\frac{1.56}{2.6}\right) * 100 = 40\%$$

where: $G_{SB} = Bulk\ Specific\ Gravity\ of\ Aggregate\ Blend$

$\gamma_{DR} = Dry\ Rodded\ Unit\ Weight = 1558.5 \frac{kg}{m^3}\ for\ Blend\ 2A$

$\gamma_W = Unit\ Weight\ of\ Water = 1000\ kg/m^3$

$VCA = Voids\ in\ the\ Course\ Aggregate$

$G_S = Max\ Specific\ Gravity\ of\ Aggregate$

Volumetric Comparisons

In this step, various combinations of oil sand, aggregates, and voids were tested to ensure we were able to produce and test the mix that we were designing. This was done by finding the maximum specific gravity (AASHTO T 209) and bulk density (AASHTO T 166) of each mix design. The total air voids for the mix were found following AASHTO T 269, and then compared to the designed air voids value. This process can be seen in Table 2 and Table 3 for a 33% (by weight) oil sand mix. Table 2 shows the actual results measured from the samples built according to the mix design in Table 3.. The percent air voids were then compared and the mix design adjusted if the target air voids were not close to the measured air voids.

All aggregates were coated with 1% hydrated lime (1% of the total aggregate weight) to help the binder better adhere to the aggregates. Initially there was trouble with the oil transfer from the oil sand to the heated aggregates. This problem was overcome by implementing a more vigorous mixing process and was not an issue with the scaled up field application project at a hot mix asphalt plant.

The percent air voids versus number of gyrations was plotted for the gyratory pucks made above. This plot can be seen in Figure 18. The plot of gyrations versus air voids confirms that there is a solid aggregate structure in the mix by asymptotically approaching a constant air void value as the number of gyrations increases.

Hamburg Wheel Tracking Device

The HWTD (AASHTO T324) was run on four different variations of the optimum aggregate structure found previously (75% ¾" and 25% ½" stockpile blend). As

mentioned in the Background section, the standards for the HWTD vary by state. For this project, it was decided that the mix must withstand 10,000 wheel passes with less than 10 mm of rut depth at 50° C. Table 4 is a summary of the results; five of the eight slabs tested passed.

In the HWTD, the oil sand mixtures showed rutting susceptibility, stripping, and moisture induced damage. Rutting susceptibility can be seen in the first linear slope region in the plot of rut depth versus wheel passes, Figure 19. The change in slope after the inflection point is attributed to moisture damage on the pavement [8]. To illustrate the variability within the mix, the number of wheel passes verses rutting depth is shown for the 33.5% oil sand mix. Even though this is the same mixture, stripping and moisture damage are evident from the plot of rut depth versus wheel passes for the left sample only.

Table 1– Unit Weight Results

Mix Name	1A	1B	2A	2B
Description	100% 19 mm Stockpile	100% 12.5 mm Stockpile	75% 19mm - 25% 12.5 mm	65% 19mm - 35% 12.5 mm
Unit Weight (kg/m3)	1664.6	1415.8	1558.5	1652.7

Table 2– Volumetric Mix Results

Max Specific Gravity of Mix		Bulk Specific Gravity of Mix		Total % Air Voids in Mix
AASHTO T 209		AASHTO T 166		AASHTO T 269
Rice 1	2.499	Gyr 1	2.416	3.4
Rice 2	2.502	Gyr 2	2.415	3.4
Avg. Gmm	2.500	Avg. Gmb	2.416	3.4

Table 3– Mix Design

	Volume %	Mass (g)	Mass %
Lime	0.6	1.5	0.6
Void	3.5	0.0	0.0
Oil Sand	36.2	77.2	33.0
Aggregate	59.7	155.4	66.4
Total	100	234.08	100

Table 4- HWTD Lab Mix Results

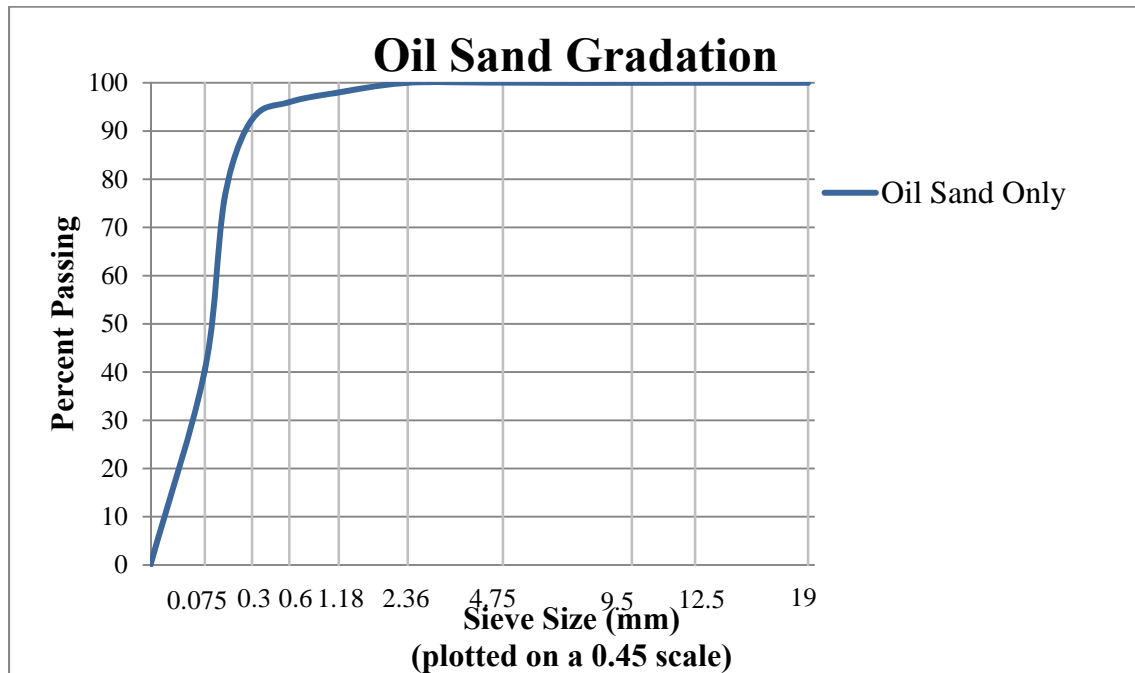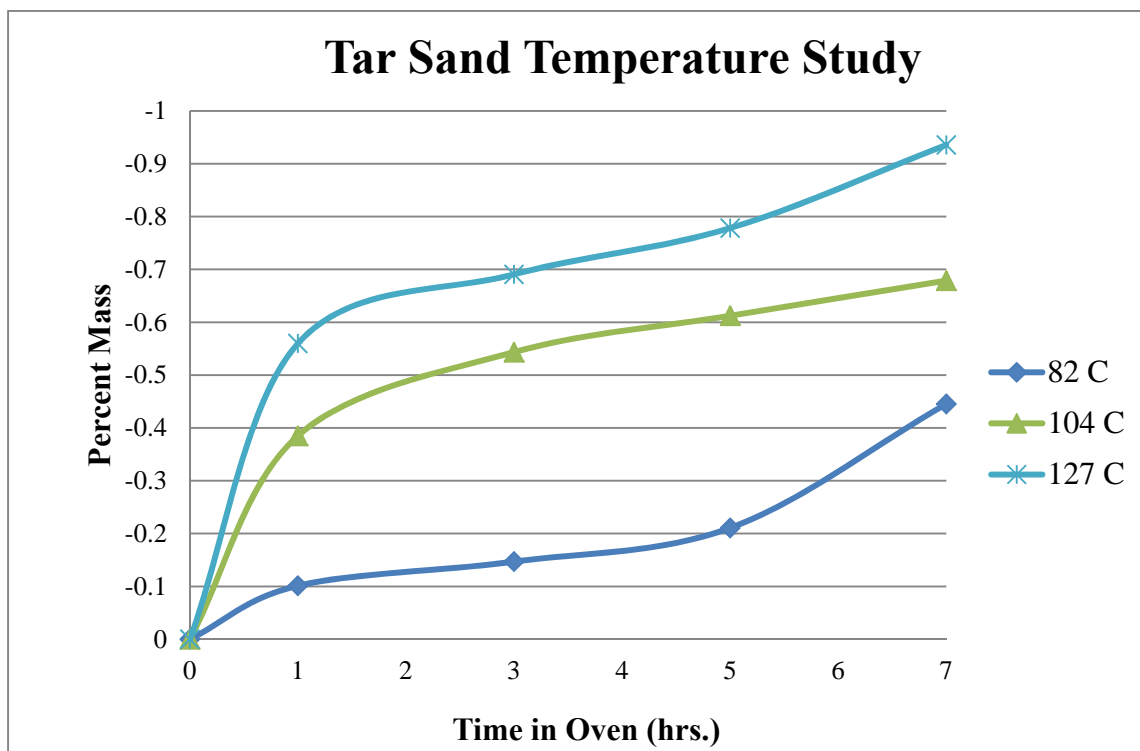| Mix ID	Percent Oil Sand (by weight)	Number of Wheel Passes Until 10 mm rut	
		Right Wheel	**Left Wheel**
1	31.5	10600	12200
2	33	12750	20000+
3	33.5	1650	10550
4	35.5	1000	760

Figure 11- Oil Sand Gradation

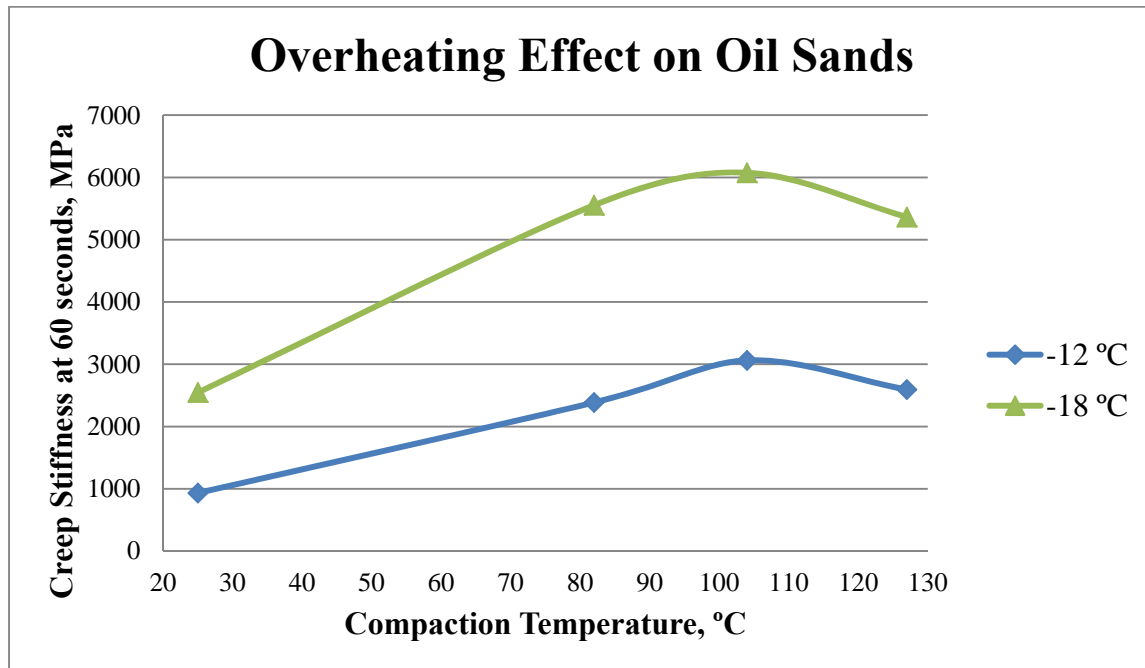**Figure 12- Tar Sand Temperature Study**

Figure 13- Overheating Effect on Oil Sand Stiffness
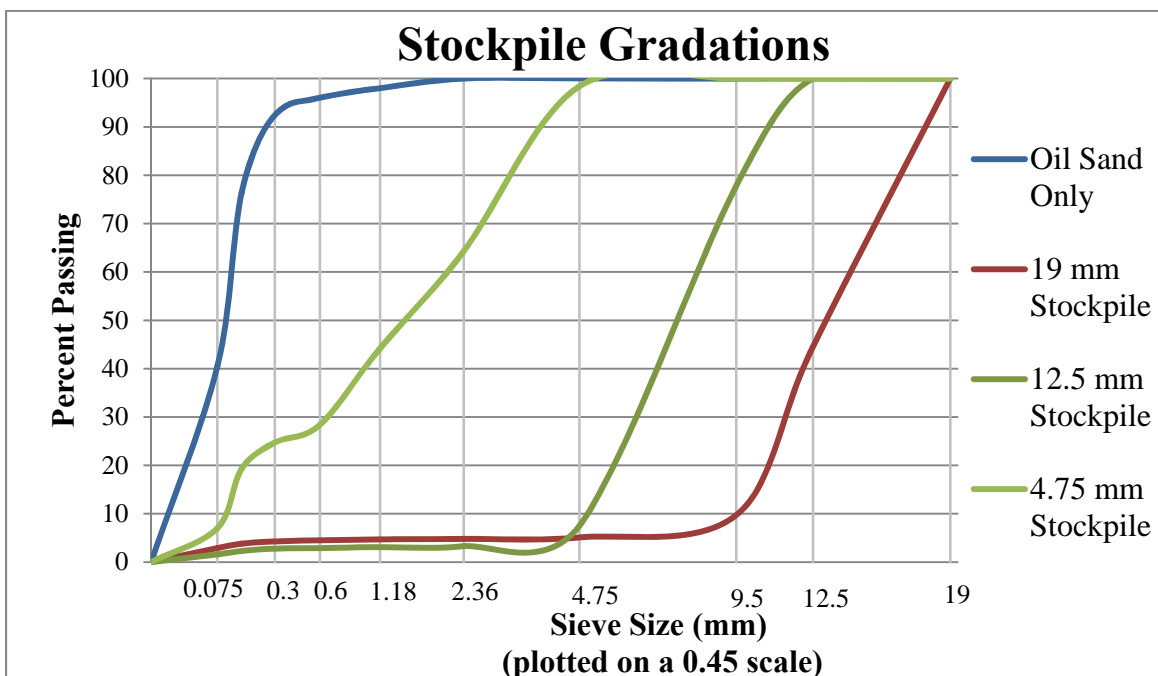
Figure 14- Stockpile Gradations
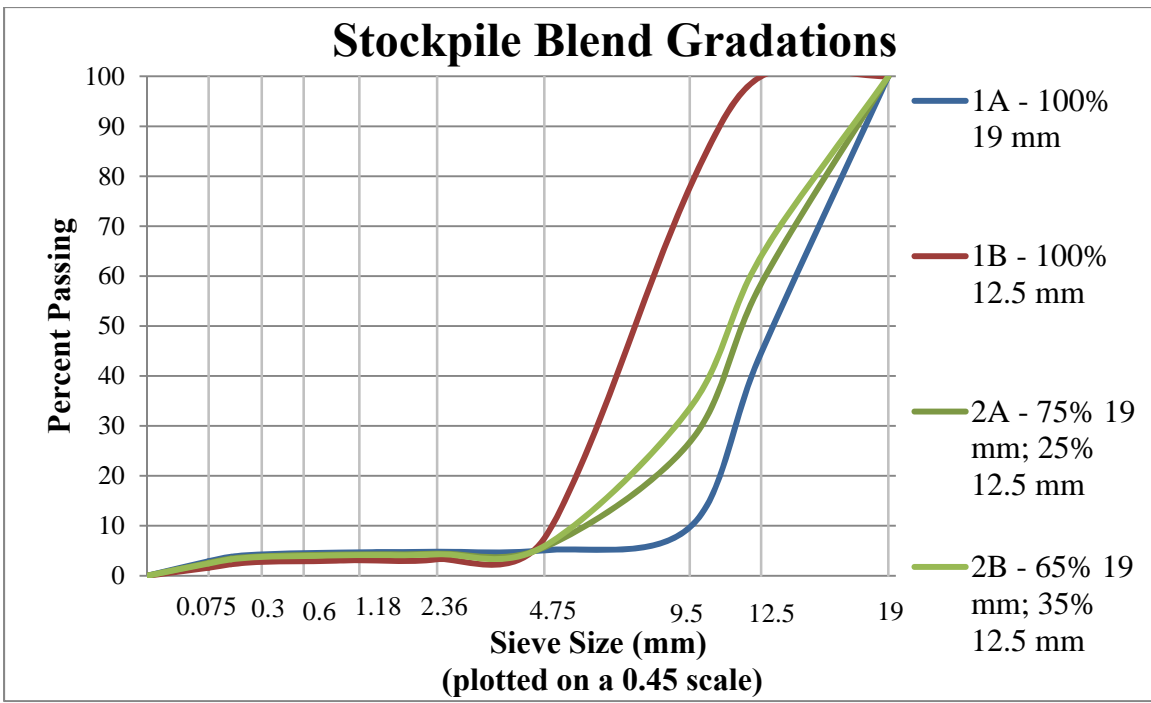
Figure 15- Stockpile Blend Gradations
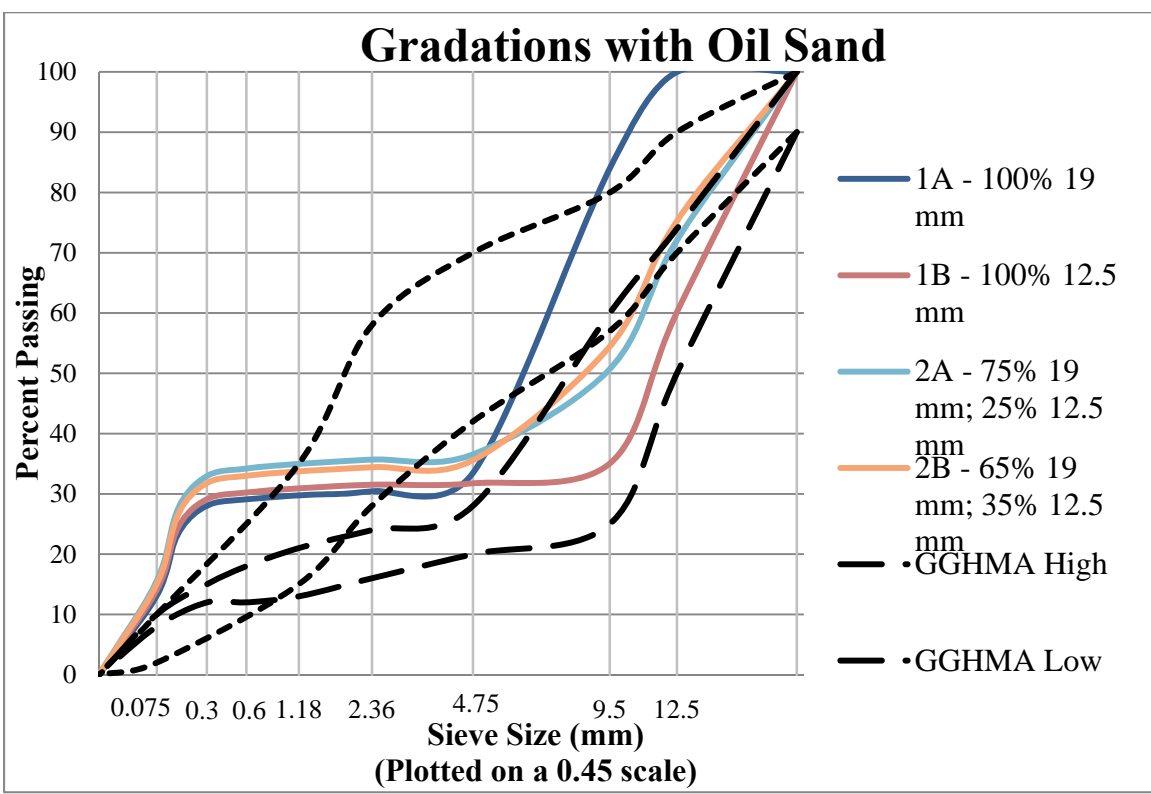
Figure 16- Gradations with Oil Sand
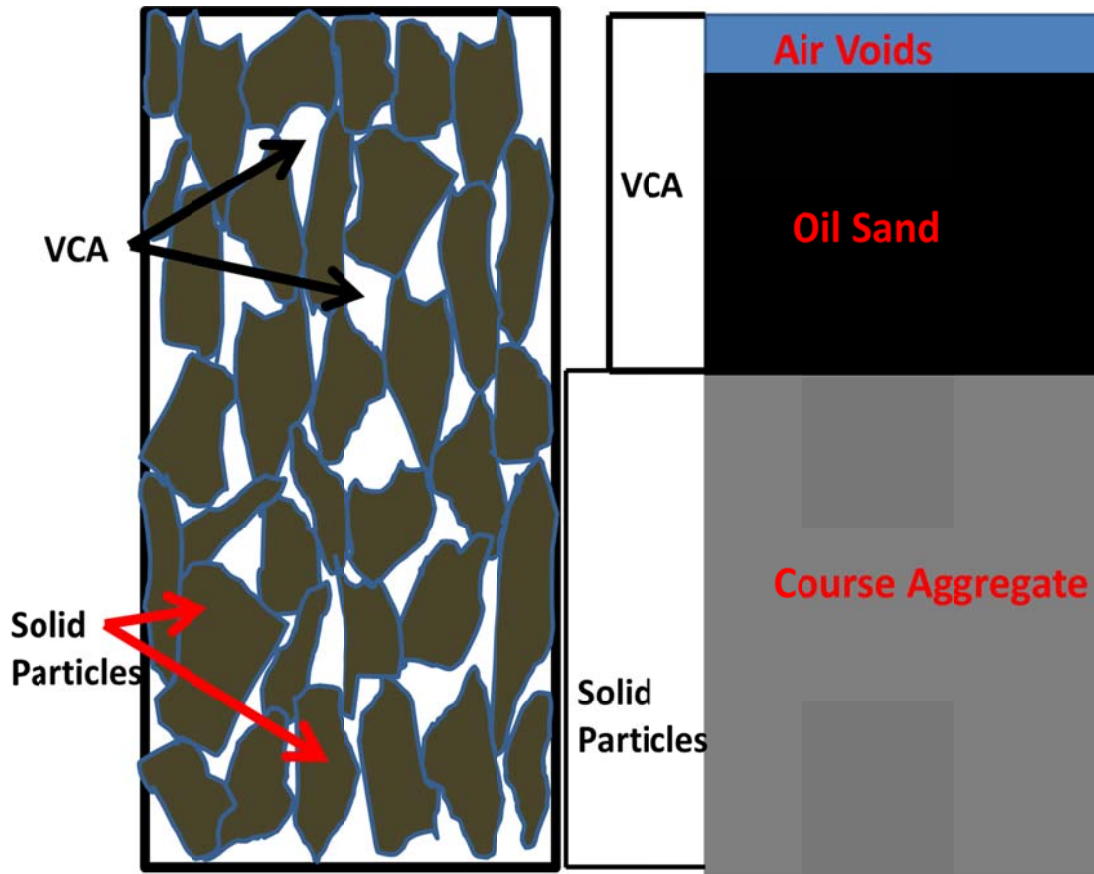
Figure 17- Volumetric Constituents
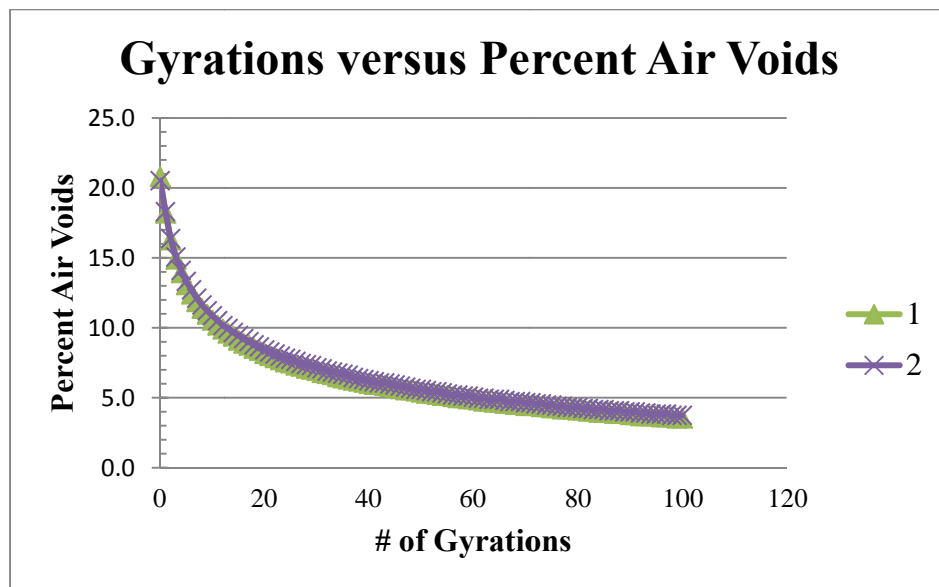
Figure 18- Compaction Plot
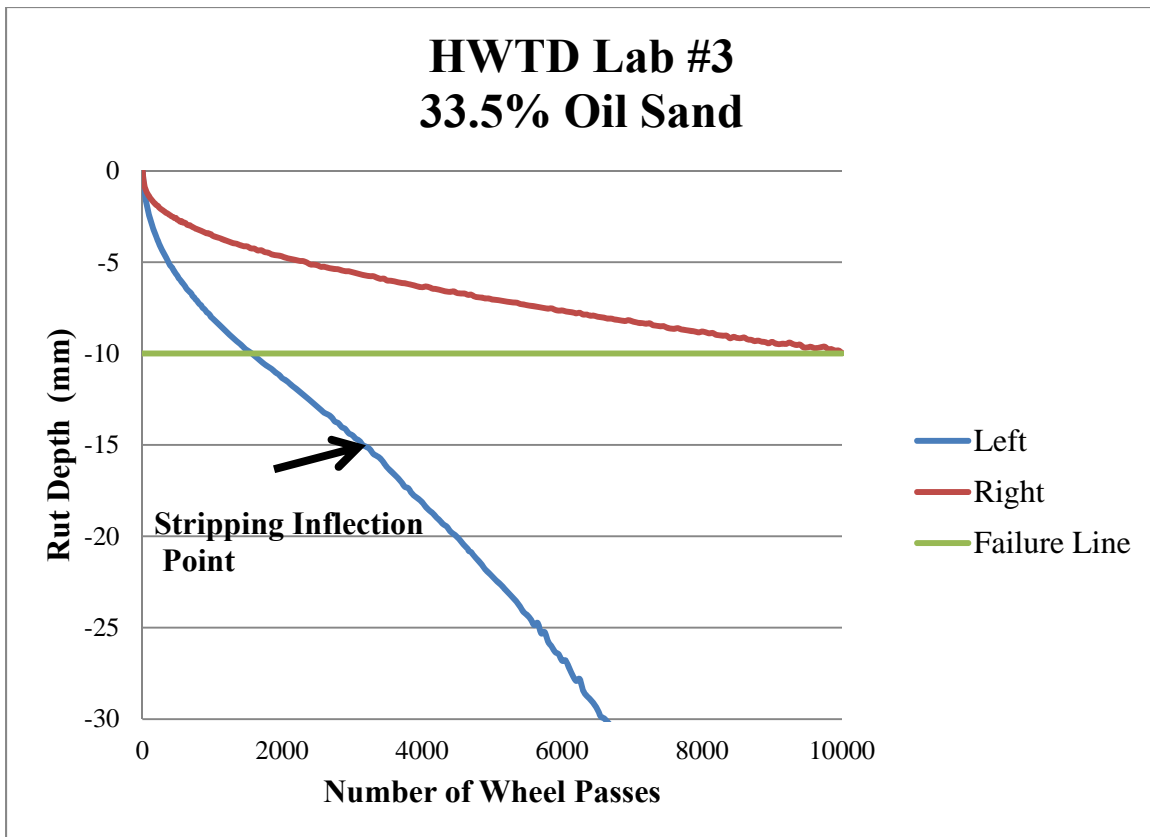
Figure 19- HWTD 33.5% Oil Sand Lab Mix Results

PMOSA SPECIFICATION SUMMARY

All of the laboratory work up to this point was used by a private consultant of the project, Timothy Biel, to develop the Plant Mixed Oil Sand (PMOSA) Specification. The PMOSA Specification is not an exact recipe; it is a procedure for the engineer to follow to create a suitable oil sand asphalt mix based on the materials available. Figure 20 is a flow chart summarizing the procedure outlined in the PMOSA Specification. The complete PMOSA Specification can be found in Appendix C.

The first step in PMOSA is to identify the available materials and ensure they meet or exceed the minimum values given within the specification. The oil sand used must contain a minimum of 10% bitumen content by ignition oven burn-off. (It should be noted that the oil sand utilized in this project had a bitumen content of 13% oil; the minimum of 10% bitumen was established by PMOSA in an effort to include as many oil sand sources as possible.) The gradation of the oil sand must have 100% passing a 12 mm (½") screen. PMOSA has detailed requirements for the coarse aggregates focusing on individual properties as well as stockpile gradations; these requirements can be found in the complete specification in Appendix C.

Once all materials have been qualified, the stockpile aggregates are blended to create a mix that has the total voids in the mineral aggregates above 40%. The total voids in the coarse aggregates in dry-rodded condition should also be found at this point.

Oil sand is then mixed with the aggregates at minimum 36% by volume of the mix. The total voids in the coarse aggregate of the mix should then be found and should be less than the total voids in the coarse aggregates in dry-rodded condition. The mix should then be tested in the HWTD according to UDOT MOI 990. In order for a mix to pass, it must have less than 10 mm of rutting at 10,000 passes. Once all of the above criterions have been met the mix can be submitted for construction [10].
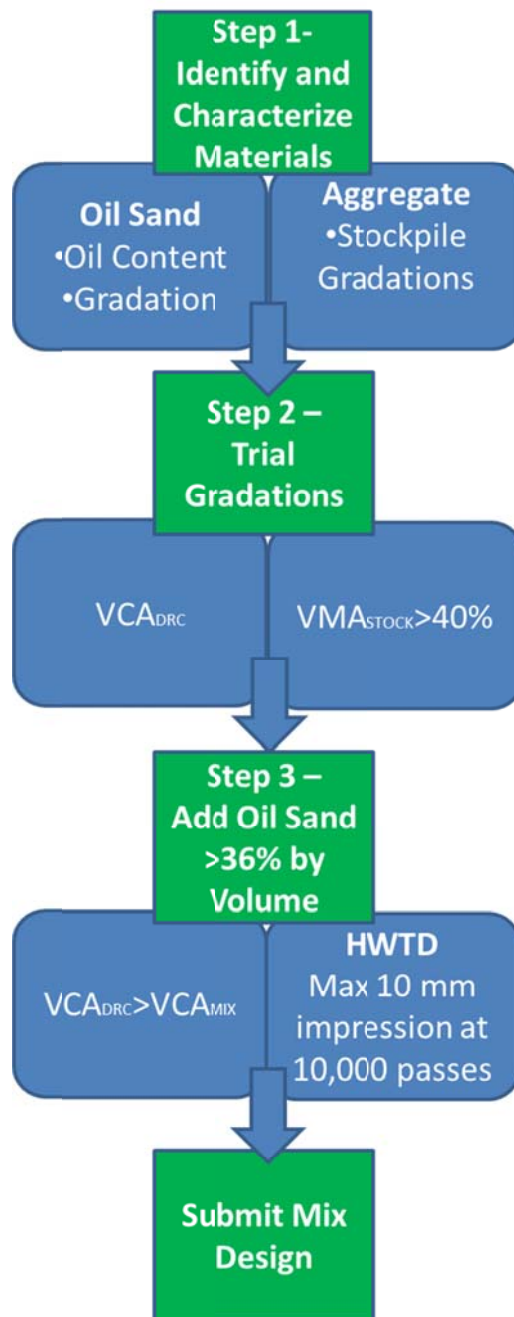
Figure 20 - PMOSA Flow Chart

FIELD PROJECT

Introduction

Using the PMOSA Specification that was developed as part of this project, a small section of Deep Creek Road was paved to determine if the laboratory mix could be reproduced at full scale. Deep Creek Road is a rural road outside of Lapoint, Utah in Uintah County. This project was done on July 19 and 20, 2011. The oil sands were mixed at a conventional hot mix plant, Staker-Parson's East Maser Plant, shown in below Figure 21.

The entire project was scheduled to be completed on July 19th, however, due to challenges in the mixing process the project was extended another day. The problem occurred as the oil sands were being dumped into a hopper at their entrance into the mixing chain. Front loader buckets of oil sand were taken from the stockpile and dropped over the hopper. In the hopper, the large mass of oil sand was self-compacting causing the hopper not to operate because oil sands had bridged over the auger at the bottom of the hopper. The mixing was then stopped and the bridging oil sand had to be pushed through using manual labor with a shovel.

Three variations of the PMOSA specification mix design were created during the field project. The first two were done intentionally to explore the ranges within the specification. The third mix was a result of a lower than normal mixing temperature on

the second day of the project, July 20th. The three variations of the PMOSA mix design were:

1. 33% Oil Sand, 50% ¾" Stockpile, 17% ½" Stockpile Mixed at 240° F

2. 40% Oil Sand, 46% ¾" Stockpile, 14% ½" Stockpile. Mixed at 240° F

3. 33% Oil Sand, 50% ¾" Stockpile, 17% ½" Stockpile. Mixed at 220° F

Laboratory Testing and Comparison

Bitumen Content

Loose mix samples were taken from each of the mixes made for Deep Creek Road and brought back to the University of Utah for laboratory testing in the Ignition Oven, BBR, HWTD, and AMPT. An ignition oven burn-off was run on two samples from each mix to find to total oil content in the mix. Table 5 shows the results from the burn-offs.

Bending Beam Rheometer

Each loose mix sample was then compacted into a short 150 mm diameter puck for the BBR specimens, a tall 150 mm diameter puck for the AMPT specimen, and linearly compacted slabs for the HWTD. The BBR was ran for each of the three field mixes and then compared to laboratory-made samples of the same mix design. The BBR results can be seen in Figure 22. The creep stiffnesses of the samples are very similar at -24° C but deviate from each other at -12° C. There is a greater variance in the creep stiffness at -12° C, where the binder is softer.

The BBR results were compared to results from binder grades often used within Utah, PG xx-22 and PG xx-28. It can be observed in Figure 23 that all of the oil sand mixes from the field project were significantly stiffer than conventional binder mixes. This is important because higher creep stiffness will result in greater cracking during the winter months and ultimately a shorter pavement life.

Hamburg Wheel Tracking Device

Fifteen HWTD slabs were made, five slabs from each of the three different mixes. Of the 15 samples tested, 7 samples passed with less than 10 mm of rutting after 10,000 wheel passes. Each of the three mix variations had at least 2 of the 5 samples pass therefore the failures were not exclusive to any mix variation. The best performing mix variation is shown in Figure 24.

Figure 24 again shows the inconsistency of the oil sand asphalt. Based on 3 of the 5 samples passing, Mix #3 has a 60% chance of performing very well against rutting. There is only a 20% chance of the mix performing very poorly and stripping because only 1 of the 5 failed quickly. It should be noted that these percentages are not a statistically rigorous prediction; however, they give an approximation of how the mix is likely to perform. Moisture damage and stripping are evident from the plot of Sample #2 and was also visibly evident during the test. Figure 25 shows the oil sand that was stripped off the slab and is now stuck to the wheel. It can be seen in Figure 25 that the oil stuck on the wheel was removed from the surface of the coarse aggregates.

Asphalt Mixture Performance Tester

The AMPT was used on the field mixes to explore the high temperature characteristics of the mix. Three 170 mm tall gyratory compacted cylinders were made from each mix variation. The 170 mm tall cylinders were then cut down to a height of 150 mm and a diameter of 100 mm, as required for the AMPT. Figure 26 shows the master curves for each mix variation based of the average values from the three samples, at a reference temperature of 20° C. The typical master curves for PG 70-28 and PG 64-34 are also plotted to show the conventional binder grades used in Utah [8]. It can be seen in Figure 26 that at high loading frequencies the dynamic moduli of the oil sand mixes are very similar to those of the conventional mixes for Utah. At lower frequencies, however, the oil sand mixes are much softer than the conventional Utah mixes. Unfortunately even with UDOT's relatively large AMPT database, there is no data available for the dynamic modulus of a PG-58-xx to compare with the sand oil.

Summary of Field Project

As of summer 2012, Deep Creek Road is still in good condition; however the original surface can no longer be seen. Following the completion of the Field Project, a chip-seal was applied by Uintah County Special Service District to prevent moisture damage. Uintah County Special Services District applies a chip-seal to all new pavements before the winter; it was not applied because of any recommendations from this project or PMOSA. Figure 27 shows Deep Creek Road as the PMOSA Field Project mix is paved.

Table 5- Ignition Oven Burn-Off Results

	Calculated Percent Binder	Average Percent Binder for Mix
1.1	4.89	4.91
1.2	4.92	
2.1	5.37	5.47
2.2	5.58	
3.1	4.81	4.82
3.2	4.83	

Figure 21- Staker-Parson's East Maser Plant
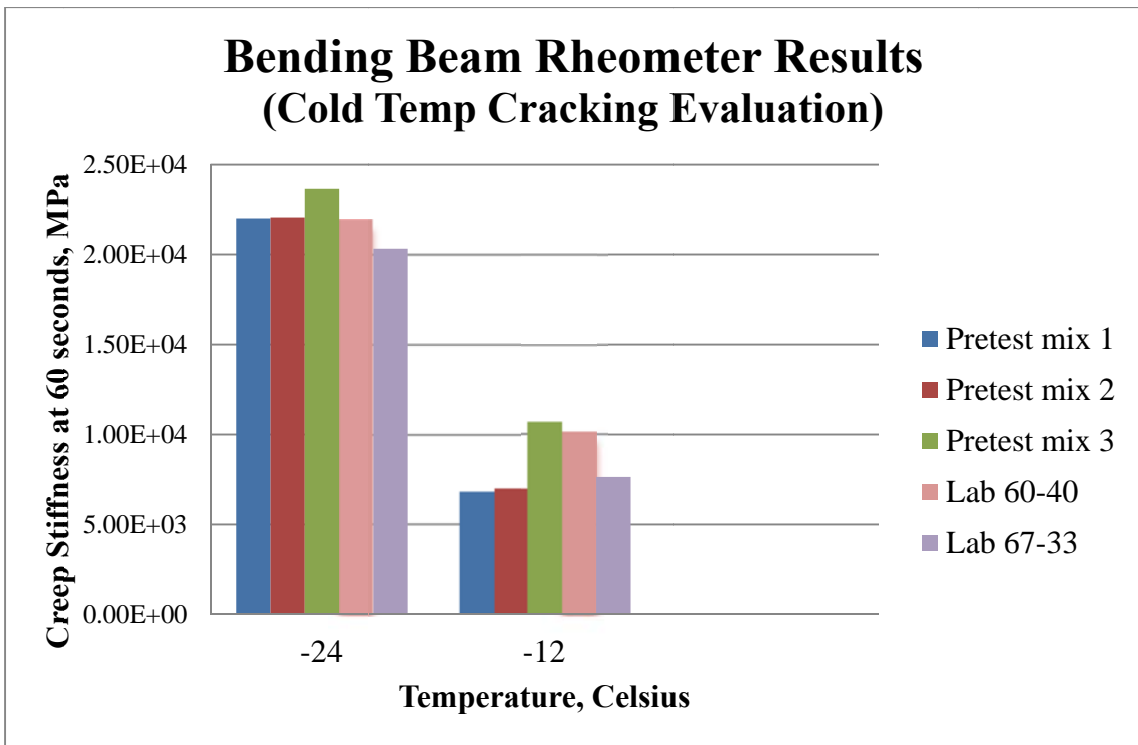
Figure 22- Field Project BBR Results
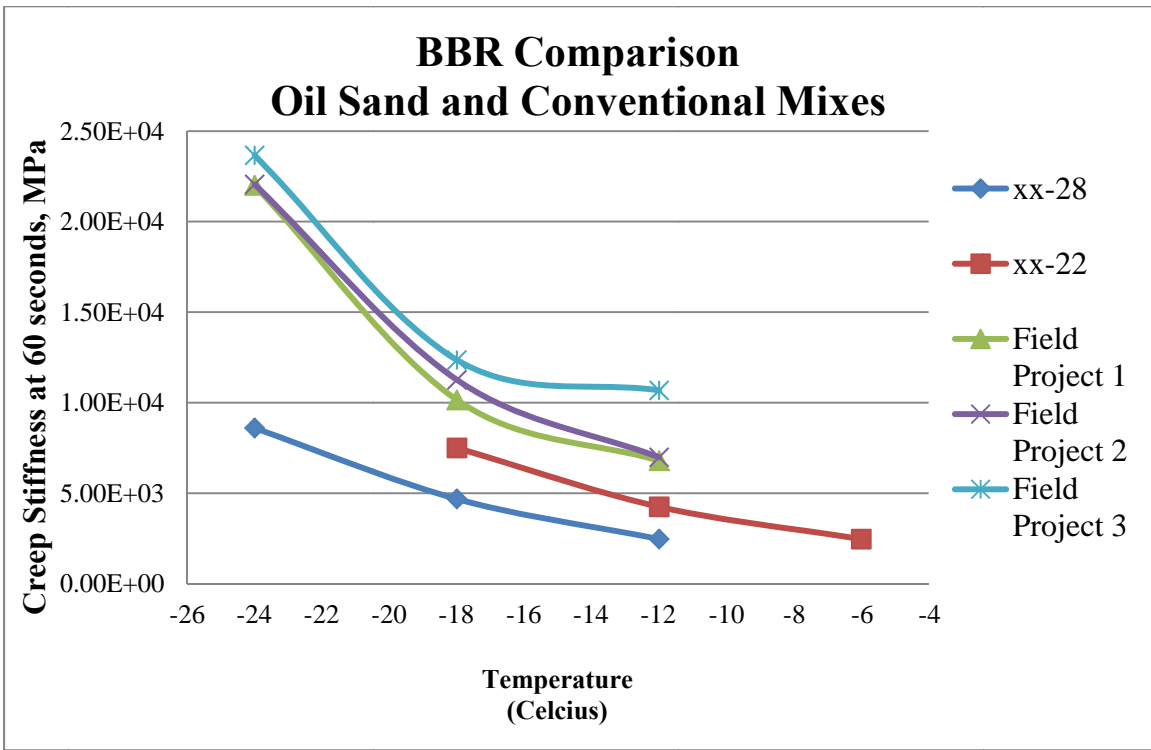
Figure 23- BBR Comparison
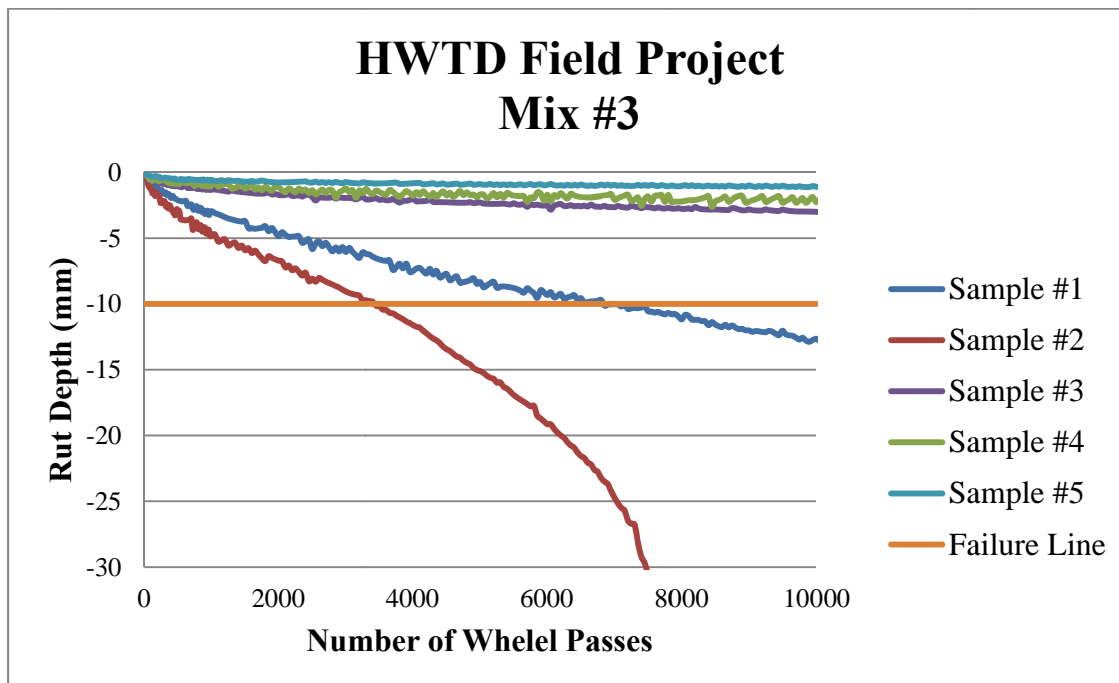
Figure 24- HWTD Field Project Results

Figure 25- Stripping on Hamburg Wheel
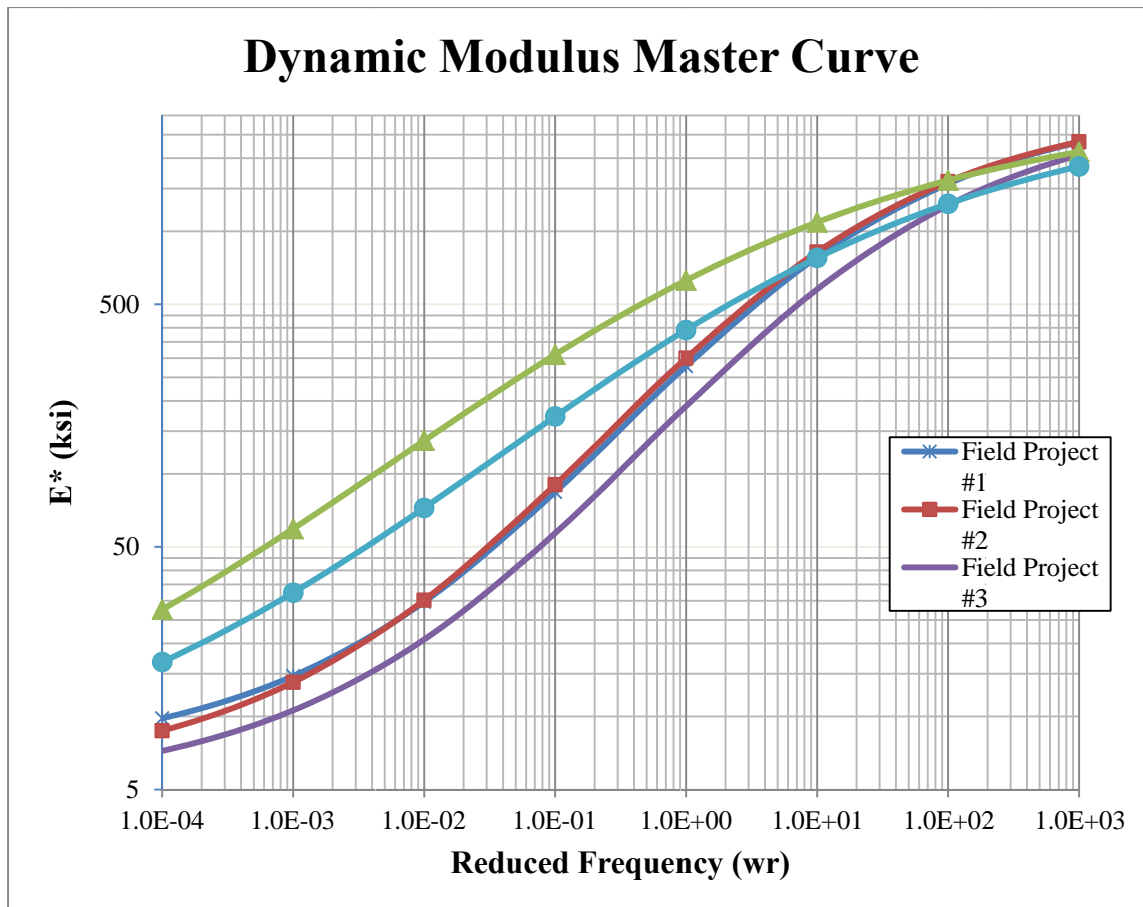
Figure 26- Field Project Dynamic Modulus Comparison

Figure 27- Deep Creek Road During the Field Project

CLOSURE

This project successfully met the objectives of developing a methodology that incorporates oil sand into a mix used as road material. The potential performance of this mix was evaluated. A field project demonstrated the feasibility of using this material.

Summary of Observations

Based on the work done to evaluate the potential performance of an oil sand roadway material, the following critical observations were made:

1. A mix consisting of 67% aggregate and 33% oil sand mix showed potential to be a viable road paving material. This blend provided enough bitumen to coat the coarse aggregates while still allowing for aggregate-on-aggregate contact to provide the structural skeleton.

2. In the HWTD, there was less than 10 mm of rut depth after 10,000 passes on 13 of the 25 slabs tested. However, the failed samples showed susceptibility to moisture-induced damage. This may be attributed to the 50° C testing temperature used for the test. UDOT specifications recommend testing at 46° C for PG-58-xx binder.

3. In the BBR, the oil sand mix had higher creep stiffness at low temperatures than mixes made with the common binder grades used in Utah. Both laboratory and field project mixes were stiffer than mixes made with PG xx-22 and PG xx-28.

4. The AMPT testing indicates that the oil sand road material results in a mix that has a lower dynamic modulus at high in-service temperatures than those tested by UDOT. The stiffness of the field project mixes were comparable at high loading frequencies, however, as frequency or temperature is increased the oil sand mixes are softer than a PG 70-28 or PG 64-32. No comparison could be made to mixes made with softer materials.

5. The field project indicates that scale up is possible, although plant modifications to address the feeding of the oil sand into the mixer might need to be addressed. The field project successfully adapted a conventional hot mix asphalt plant to incorporate oil sand with only minor delays.

6. The performance testing indicates that oil sand mixtures result in a material with a higher variability. This variability was observed within samples from identical mixes, exemplified by the scattered results of the HWTD.

Conclusions

From the previously mentioned observations and the work done throughout this project, the following conclusions were made:

1. The use of performance testing allows for the development of an asphalt mix where the conventional asphalt binder is replaced with oil sand to produce a

working roadway material. A similar approach could be used to incorporate other unconventional materials.

2. The oil sand mix material is softer at high temperatures and stiffer at low temperatures than conventional HMA mixes used in Utah. This indicates that this material might not be suitable for high-value roads, such as interstate highways; however it could be used on lower traffic volume roads. On a per-mile basis, low traffic volume roads represent the majority of the transportation network.

3. The variability in the test results indicates that there is a narrow window for successful design. The inherent variability from the oil sand being a natural unmodified material is believed to be a large contributor to the variability.

4. There is a large economic and environmental advantage to using oil sand mixes as a roadway material. Oil sand mixes require a lower mixing temperature than HMA and therefore save on fuel costs and emissions.

Recommendations for Future Work

Over the course of the research, the following where found as areas that need to be further explored to maximize the use and benefit of an oil sand pavement.

1. Continue monitoring the field performance of the projects completed using PMOSA. The ultimate deciding factor for the use of oil sand pavements will be if it can perform in the field without premature failure.

2. Explore adding new components into the mix to improve performance. The addition of virgin asphalt binder into the mix may help the material meet performance measures at the temperature ranges of conventional binders. Even

though the addition of a small amount of virgin binder decreases the economic and environmental gain of the oil sand mix.

3. Investigate how the incorporation of material such as Recycled Asphalt Pavements (RAP) and Recycled Asphalt Shingles (RAS) might improve the mix. RAP and RAS both contain aged bitumen that could help increase the high-temperature stiffness of the mixture.

4. Investigate environmentally sound extraction methods to create higher yield bitumen content. It may be possible to remove a portion of the sand from the oil with relatively little effort compared to the full extraction into crude oil. An oil sand with less sand allows for more sources to be used as well as a better fit into conventional gradation windows.

APPENDIX A

PLANT MIXED OIL SAND ASPHALT (PMOSA) SPECIFICATION

SPECIAL PROVISION

PROJECT #

SECTION xxxxx

PLANT MIXED OIL SAND ASPHALT (PMOSA)

Add Section xxxxx:

PART 1   GENERAL

1.1   SECTION INCLUDES

A.   Products and procedures for mixing, laying, and compacting a surface course of one or more layers of plant mixed oil sand asphalt comprised of raw oil sands, coarse aggregate, lime and other additives.

1.2   RELATED SECTIONS

A.   *[Placeholder for related project specifications]*

1.3   REFERENCES

A.   AASHTO R 46: Designing Stone Matrix Asphalt

B.   AASHTO T 11: Materials Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing

C.   AASHTO T 19: Unit Weights and Voids in Aggregate

D.   AASHTO T 27: Sieve Analysis of Fine and Coarse Aggregates

E.   AASHTO T 30: Mechanical Analysis of Extracted Aggregate

F.   AASHTO T 89: Determining the Liquid Limit of Soils

G.   AASHTO T 90: Determining the Plastic Limit and Plasticity Index of Soils

H.   AASHTO T 96: Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine

I.   AASHTO T 104: Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

J.	AASHTO T 112: Clay Lumps and Friable Particles in Aggregate

K.	AASHTO T 195: Determining Degree of Particle Coating of Bituminous-Aggregate Mixtures

L.	AASHTO T 209: Maximum Specific Gravity of Bituminous Paving Mixtures

M.	AASHTO T 255: Total Moisture Content of Aggregate by Drying

N.	AASHTO T 308: Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method

O.	AASHTO T 312: Method for Preparing and Determining the Density of Hot-Mix Asphalt (PMOSA) Specimens by Means of the Superpave Gyratory Compactor

P.	AASHTO T 335: Determining the Percentage of Fractured Particles in Coarse Aggregate

Q.	ASTM D 2950: Standard Test Method for Density of Bituminous Concrete in Place by Nuclear Methods

R.	ASTM E 178: Practice for Dealing with Outlying Observations

S.	UDOT 2008 Standard Specifications - Section 02741: Hot Mix Asphalt

	T.	UDOT 2008 Standard Specifications - Section 02746: Hydrated Lime

U.	UDOT 2008 Standard Specifications - Section 02748: Prime Coat/Tack Coat

V.	UDOT Materials Manual of Instruction, Part 8

## 1.4	DEFINITIONS

A.	Oil Sands
	1.	A mined material comprised of natural asphalt and sand.

B.	Voids Filled with Mortar (VFM)
1.	Percentage of VCA_{DRC} filled with Oil Sands and material passing #4 screen, by total volume of VCA_{DRC}.

C.	Voids in the Mineral Aggregate Stockpile (VMA_{STOCK})
	1.	$VMA_{STOCK} = (G_{SB}*\gamma_W - \gamma_S)/(G_{SB}*\gamma_W) * 100$ where:

G_{SB} = Bulk Specific Gravity of the total stockpile aggregate

γ_W = unit weight of water

γ_S = unit weight of the total stockpile aggregate fraction in the dry rodded condition

D.   Voids in the Coarse Aggregate (VCA_{MIX} and VCA_{DRC})

1.   As per R46, articles 8.2 and 9.1.

1.5   SUBMITTALS

A.   Oil Sand Source Verification Data as per article 2.1

B.   Volumetric Mix Design data as per article 2.5.

C.   Contractor Quality Control Data as per article 3.3

1.6   ACCEPTANCE

A.   A lot equals the number of tons of PMOSA produced during each production day. The Engineer will:

1.   Evaluate each lot based on a minimum of 4 samples for gradation, air voids and VCA_{MIX}.

2.   Take random samples from behind the paver. (UDOT Materials Manual of Instruction Part 8-984: Sampling Methods), and determine random numbers/locations from a random numbers table or generator. (UDOT Materials Manual of Instruction Part 8-981: Random Sampling)

a.   Dispute Resolution Sampling – Increase sample sizes to accommodate paired-T testing. Split additional material with contractor designated lab and continue until testing discrepancies between labs are identified and resolved as defined in this Section, article 1.7 (UDOT Materials Manual of Instruction, Part 8: Chapter 4, Appendix C).

3.   Inform the Contractor of the time and place for the sample not more than 15 minutes prior to the sampling.

4.   Conduct the following tests on the produced mix for acceptance:

a.   Aggregate gradation: One test per 500 mix tons on the coarse aggregate cold feed. AASHTO T 30

b.   Maximum Specific Gravity: One test per 500 tons in conjunction with VCA determination. AASHTO T 209

c.   Air Voids in the Mix: One per 500 tons. AASHTO T 312

d. VCA_{DRC}: 1 test per 500 tons on cold-feed samples taken at the same time as mix samples for the first week of production. AASHTO R 46

e. VCA_{MIX}: One per 500 tons on cold-feed samples taken at the same time as mix samples. AASHTO R 46

5.   Conduct the following tests on the produced mix:

a.   Asphalt Binder Content: One per 500 tons using ignition oven. AASHTO T 308

b.   Aggregate gradation: One test per 500 tons on the residue of the ignition oven tests. AASHTO T 30

6.   Add the lot to the previous day's production if the minimum number of samples cannot be obtained for the final day's production and evaluate with the appropriate sample size.

7.   Add the lot to the next day's production if the minimum number of samples cannot be obtained, and evaluate with the appropriate sample size.

B.   Obtain samples for density correlation and thickness.

1.   Obtain one core per 500 tons, randomly as instructed, and in the presence of the Engineer within two days after the pavement is placed.(UDOT Materials Manual of Instruction Part 8-981: Random Sampling, UDOT Materials Manual of Instruction Part 8-984: Sampling Methods)

2.   Obtain 5 cores from first test strip, randomly as instructed and in the presence of the Engineer within 4 hours after the pavement is placed. (UDOT Materials Manual of Instruction Part 8-981: Random Sampling, UDOT Materials Manual of Instruction Part 8-984: Sampling Methods) Use of dry ice to facilitate cooling is acceptable

3.   Move transversely to a point one foot from the edge of the pavement if the random location for cores falls within one foot of the edge of the overall pavement section (outer part of shoulders).

4.   Fill core holes with PMOSA or high AC content cold mix and compact.

5.   Use the average of the Maximum Specific Gravity tests for each lot to determine density of cores.

6.   Determine thickness of cores according to ASTM D 3549.

C.   Lot Acceptance: The Engineer conducts the acceptance testing for coarse aggregate gradation (AASHTO T 30) and in-place density (ASTM D 2950).

1.   Gradation: The engineer accepts a lot when the average of all gradation tests from mix sampling is between the limits of Table 1 and no individual test deviates from the limits by more than 2%. If no gradation tests are taken, gradation is not used for acceptance.

2.   In-Place Density: The in-place target density for determining acceptance is 93.0 percent of Maximum Specific Gravity density, AASHTO T 209. In-place density is based on field nuclear density values obtained in accordance with ASTM D 2950 correlated to cores obtained from initial test strip. The engineer accepts a lot when the average of all density tests is between the limits of Table 1 and no individual test deviates from the limits by more than 2%.

3.   The Engineer will calibrate the Nuclear Density Gauges for Acceptance Testing with project cores one every 15,000 tons.

D.   Smoothness Tests

1.   Provide uniform grade and smoothness. The maximum vertical
        distance from the pavement surface to a straight edge is:
A.   1/8-inch in 10-feet parallel to centerline.
B.   1/4-inch in 10-feet perpendicular to centerline except at crosssection
grade breaks.

2.   Plane off high surface distortions. Coat planed surfaces with a CSS-1
emulsion.

E.   Cease production when any two out of three consecutive lots meet one of
the following:

1.   Air voids at N_{des} averaged for each lot are less than 2.5 or greater than 4.5
percent.
2.   Production control requirements of Table 1 are not met. Submit a
corrective action plan to the Engineer before production continues indicating the
changes in production procedures that will be implemented to correct the
deficiencies.

Table 1	
Mix Parameter Upper and Lower Limit Determination	
Parameter	**UL and LL**
Coarse Aggregate Control Sieves (All sieves from Table 4)	Target Value ± 4.0%
Oil Sand Ignition Oven Value (uncorrected burn)	Minimum of Source Acceptance Value – 0.5%
Density	Lower Limit: Target Value - 2.0% Upper Limit: Target Value + 3.0%
VCA_{MIX}	< VCA_{DRC}
Binder Content	Target Value ± 0.5%

1.7   DISPUTE RESOLUTION

A.   Do not continue production related to the material type in question without
concurrence from the Engineer or until differences in the test results are
resolved.

B.   Submit an engineering analysis within one week of receipt of test results or 24 hours prior to performing any work that may prevent the evaluation, correction, or removal of the lot in question.

1.   Engineering Analysis must be based on test results performed by an AASHTO accredited lab that has performed a split-sample process with the Department and must be submitted by a licensed Professional Engineer.

C.   Include at a minimum the following items in the engineering analysis:

1.   Data supporting the Contractor's test results. Data must be based on project quality control testing.
a.   Contractor's test data for the disputed results, along with all supporting test data and calculations for calculated values such as Bulk Specific Gravity, Maximum Specific Gravity, and Ignition Oven results for disputing VMA.
b.   Split-sample testing performed within the applicable contract
c.   Successful Laboratory Correlation information when required by material specification
2.   Procedures or issues leading to disputed acceptance test results.

D.   If the Engineering Analysis is deemed valid and errors are identified that cannot be corrected, the Engineer may choose to evaluate the lot using the Hamburg Wheel Tracker (AASHTO T 324), using the following:

1.   Use 5 stratified random samples cut from the roadway
2.   The Resident Engineer and the Contractor will negotiate the status of the lot and associated pay adjustment based on test results that represent the following:
a.   Stripping Potential
b.   Rutting Potential

PART 2   PRODUCTS

2.1   OIL SAND

A.   Use Oil Sand with minimum 10% bitumen content.

B.   Source Qualification: Submit the following to the Engineer for review. Engineer will review and respond within 1 week regarding equivalent approval or rejection. Use an UDOT, AMRL or WCTG accredited lab; or University of Utah Asphalt lab for all test results. Approval of source does not constitute approval of mix design. All requirements of Article 2.5 must be met, regardless of Oil Sand source.

1.   Supplier must show tests results on a virgin oil sand mix (oil sand ore and virgin aggregate only) designed to this specification showing dynamic modulus master curve from AMPT meets the following:

Frequency	Dynamic Modulus (E*), ksi, 20°C
1.0E+01	900 max
1.0E- 02	20 min

3.   Test results on minimum 5 samples showing bitumen content is minimum 10% of oil sands and sufficient to fully coat all aggregate for proposed mix design using lime coated virgin aggregate.

4.   Test results on minimum 5 samples showing corresponding extracted binder content and ignition oven loss values. Ignition oven loss value is comprised of bitumen loss and clay/silt/aggregate loss. These results will be used for project quality assurance.

5.   Test results on minimum 5 samples showing sand gradation meeting the following:

Table 2	
Sieve	**Percent Passing**
½"	100%
¼"	98% min
#200	15% max

C.   Store and manage Oil Sand stockpile to minimize caking and settlement.

2.2   LIQUID ASPHALT CEMENT

A.   Do not add liquid asphalt cement to the PMOSA mix, in any amount, under any conditions.

2.3   COARSE AGGREGATE

A.   Crusher processed virgin aggregate material consisting of crushed stone, gravel, meeting gradation requirements of Table 4. AASHTO T 27

B.   Use the requirements in Table 3 to determine the suitability of the coarse aggregate.

Table 3
Aggregate Properties - PMOSA

Test Method	Test No.	Requirement
One Fractured Face	AASHTO T 335	85% min. (1 inch and ¾ inch), and 90% min. (½ inch and $^3/_8$ inch)
Two Fractured Face	AASHTO T 335	80% min. (1 inch and ¾ inch), and 90% min. (½ inch and $^3/_8$ inch)
Flakiness Index	UDOT MOI (Based on $^3/_8$ inch and above)	25% max.
L.A. Wear	AASHTO T 96	40% max.
Plasticity Index	AASHTO T 89 and T 90	0 max.
Unit Weight	AASHTO T 19	75 lb/cu. ft. min.
Soundness (sodium sulfate)	AASHTO T 104	16% max. loss with five cycles
Clay Lumps and Friable Particles	AASHTO T 112	2% max.

C.   Meet ¾" gradation requirements in Table 4. (AASHTO T 11, AASHTO T 27)

Table 4			
Aggregate Gradations (Percent Passing by Dry Weight of Aggregate)			
Sieve Size		**1 inch**	**¾ inch**	**½ inch**
Control Sieves	**1½ inch**	100.0		
	1 inch	90.0 - 100.0	100.0	
	¾ inch	<90	90.0 - 100.0	100.0
	½ inch	Report	<90	90.0 – 100.0
	⅜ inch	Report	Report	<90
	No. 4	<7	<8	<8
	No. 200	<3	<3	<3

2.4   ADDITIVES

A.   Hydrated Lime - If used, meet the requirements of UDOT Standard Specifications Section 02746.

2.5   JOB-MIX DESIGN

A.   Plant Mixed Oil Sand Asphalt Mix Design:

1.   Use a UDOT Laboratory Qualification Program HMA qualified laboratory.

2.   Use a Superpave Gyratory Compactor approved in accordance with UDOT Materials Manual of Instruction Part 8-961: Guidelines for Superpave Gyratory Compactor Protocol.

3.   Use oil sand content in accordance with Table 6.

4.   Combine oil sand with coarse aggregate meeting requirements of Table 6.

a.   Select a trial Coarse Aggregate Gradation

b.   Determine VCA of contractor selected coarse aggregate blend, including material passing #4 screen.

c.   Add contractor selected percentage of oil sands and mix at temperatures in accordance with Table 6.

d.   Determine air void content of mix specimen prepared using gyratory compactor and gyrations in accordance with Table 5.

e.   Verify VCA_{DRC} is greater than VCA_{MIX}.

f.   Adjust coarse aggregate gradation or oil sand content as necessary and repeat steps a through c to meet Table 4 and Table 6.

5.   Perform 5 laboratory ignition oven loss tests (AASHTO T 308). Report un-calibrated but temperature corrected values.

B.   Submit the Volumetric Mix Design data to the Engineer for verification at least 5 working days before beginning paving. Do not begin paving until verification is complete.

1.   Include all information regarding selection of design aggregate structure showing the target values of percent passing on all control sieves listed in Table 4 and a summary of ignition oven results.

2.   Provide information that the aggregate proposed for use meets the requirements of Table 3.

3.   Supply QC data for target job mix gradation selection. Use those target values for price adjustments.

4.   Run 4 sets of 2 Gyratory specimens at the design oils sand content to verify the optimum oil sand content and all other design requirements after the design is complete.

C.   Moisture Susceptibility

1.   Hydrated Lime is not required for this project but may be used to meet requirements of Table 6.

.

D.   Use gyratory mixing and compaction temperatures in accordance with Table 6.

E.   The Engineer 's designated lab verifies the Plant Mix Oil Sand Asphalt Mix Design.

F.   Comply with the following requirements for Plant Mix Oil Sand Asphalt Mix Design.

Table 5	
Oil Sand Asphalt Mix Design – **PMOSA Compaction Parameters**	
Design Gyrations	**% of G_{mm}***
75 min, 100 max	96.0

* G_{mm}: Maximum specific gravity of Mix.

Table 6 Plant Mix Oil Sand Asphalt Mix Design Requirements	
PMOSA design mixing and compaction temperatures	220 ± 10 deg F
Oil Sand Content in Mix	36% by volume of mix, minimum
Voids In Mineral Aggregate - Stockpile	40% < VMA_{STOCK}
VCA_{MIX}	< VCA_{DRC}
Hamburg Wheel Tracker UDOT MOI 990	Maximum 10 mm impression at 10,000 passes*

*HWT Minimum Pass requirement may be reduced at the Engineer's discretion.

2.6   RESEARCH SAMPLING

A.   The Engineer will pull two research samples daily. Each sample will be approximately 50 lbs and will be taken from the paver hopper or windrow for non-project related testing.

2.7   CONTRACTOR INITIATED CHANGES IN PLANT MIX OIL SAND ASPHALT MIX DESIGN

A.   Submit all requests, in writing to Engineer, at least 12 hours prior to incorporating changes into production.

B.   Submit a field volumetric mix design for all target changes.

1.   Include documentation supporting correlation between suggested target changes and mix design volumetric requirements. Engineer acceptance and/or Contractor QC testing data is acceptable.
2.   Field volumetric mix design verification consists of 3 sets of 2 gyratory specimens run at the new target gradation, asphalt binder content, or both. The Engineer's previous acceptance tests are acceptable for field verification.
3.   The Engineer provides written concurrence of the verified field volumetric mix design if the field volumetric mix design meets the volumetric requirements.
4.   Submit a new laboratory volumetric mix design from a UDOT qualified laboratory if the field volumetric mix verification does not meet the volumetric requirements. Allow at least 4 working days for verification.
5.   The Engineer performs up to two volumetric mix design verifications at no cost to the Contractor. The Engineer charges $3,000 for each additional laboratory or field verification required including all laboratory or field volumetric mix design verifications required due to contractor initiated target changes.

C.   Submit a new laboratory volumetric mix design if changes occur in the aggregate, lime or oil sand source.

D.   Do not make changes to production mix until request is reviewed and verified.

PART 3   EXECUTION

3.1   ADDING HYDRATED LIME

A.   If Hydrated Lime is incorporated in the mix, use Method A, Lime Slurry; or Method B, Lime Slurry Marination: Refer to UDOT Standard Specifications Section 02746.

3.2   PMOSA PLANT

A.   Provide:
1.   Positive means to determine the moisture content of aggregate.
2.   Positive means to sample all material components.
3.   Positive means to sample final cold-feed blend immediately to entering dryer.
4.   Sensors to measure the temperature of the PMOSA at discharge.
5.   The ability to maintain discharge temperature of the mix in accordance with the mix design.
6.   Capability of maintaining ± 5% tolerance on component percentages in final mix.

B.   Oil Sand Introduction System:
1.   Break down raw oil sands to pass a 6" screen.
2.   Oil sands are a compactable material. Introduce oil sand in a manner that does not cause compaction of the material. Use of tapered bins tends to promote compaction and bridging. It is recommended that the contractor consider means to minimize compaction or "fluff" material at the belt.
a.   Material rejected or time loss due to stoppage of oil sand introduction is the responsibility of the contractor.
3.   Introduce oil sands through either cold feed or rap collar.
4.   Do not heat raw oil sands above limits of Table 5.

3.3   PMOSA PRODUCTION

A.   Dry aggregate to an average moisture content of not more than 0.2 percent by weight. Verified by AASHTO T 255. Adjust burners to avoid damage or soot contamination of the aggregate.

B.   Coat with oil sands natural asphalt binder 100 percent of the particles passing and 98 percent of the particles retained on the No. 4 sieve.
1.   Verified by AASHTO T 195.
2.   Discontinue operations and make necessary corrections if material is not properly coated.

C.   Maintain average temperature of the PMOSA below identified mixing and compaction temperature, as defined Table 5.
1.   Immediately cease production and make operational corrections to meet project tolerances if temperature exceeds limits for more than one 5 minute period in a 2 hour period of production.

D.   Contractor Mix Quality Control
1.   Perform 4 ignition oven loss tests (AASHTO T 308) and gradations (AASHTO T 11) on raw oil sands per lot.

a.   Cease production and submit new source acceptance testing and volumetric mix design if lot average for either ignition oven loss is outside limits of Table 1 or gradation is outside limits of Table 2.

2.   Perform 4 gradations (AASHTO T 308) and moisture contents (AASHTO T 255) on coarse aggregate feed per lot

a.   Cease production and make operational corrections to meet project tolerances if lot average for gradation is outside limits of Table 4 or moisture content exceeds requirement of article 3.3 A.

3.   Perform 4 gradations and asphalt cement contents (AASHTO T 308) on the total mix per lot. Report test results to the engineer on a daily basis.

4.   Perform a visual inspection of the first five loads prior to leaving plant for coating requirements in accordance with Article 3.3B. If all 5 loads are properly coated, visually inspect every 5th load prior to leaving plant for coating requirements in accordance with Article 3.3B .Provide daily written summary to the Engineer of lot and load number, coating observations, and resultant actions taken to address coating deficiencies.

E.   Submit at the end of each day to the engineer, a plant production summary daily that includes mix component percentages for approximately every 15 minutes of production.

1.   Immediately cease production and make operational corrections to meet project tolerances if component percentage varies by more than 5% of total mix weight for more than one 15 minute period.

3.4   SURFACE PREPARATION

A.   Locate, reference, and protect all utility covers, monuments, curb and gutter, and other components affected by the paving operations.

B.   Remove all moisture, dirt, sand, leaves, and other objectionable material from the prepared surface before placing the mix.

C.   Allow sufficient cure time for prime coat/tack coat prior to placing PMOSA. Refer to UDOT Standard Specifications Section 02748.

3.6   TEST STRIP

A.   Place a maximum 400 ton test strip demonstrating the capability to produce, lay and compact the PMOSA in compliance with this specification.

B.   If test strip does not meet full compliance with this specification, the test strip is considered rejected. Submit a corrective action plan to the Engineer

outlining changes to production and placement operations that will bring the materials into compliance with this specification.

1.   Remove test strip or submit an Engineering Analysis in conformance to the requirements of the Dispute Resolution section addressing whether or not the test strip can remain in place.

C.   Repeat test strip process until successful test strip is placed. Do not begin full production until successful test strip is achieved.

3.7   SURFACE PLACEMENT

A.   Provide a 3:1 (horizontal to vertical) sloped edge adjacent to the next lane to be paved when full-width or echelon paving is impractical and more than one pass is required.

B.   Adjust the production of the mixing plant and material delivery until a steady paver speed is maintained.

C.   Do not allow construction vehicles, general traffic, or rollers to pass over the uncompacted end or edge of freshly placed mix until the mat temperature drops to a point where damage or differential compaction will not occur.

D.   Taper the end of a course subjected to traffic at approximately 50:1 (horizontal to vertical).
1.   Make a transverse joint by saw or wheel cutting and removing the portion of the pass that contains the tapered end.
2.   Tack the contact surfaces before fresh mix is placed against the compacted mix.

E.   Use a Material Transfer Vehicle (MTV) to apply all courses of PMOSA. Use an MTV that internally performs additional mixing of the PMOSA mix and then deposits material into the paver at a uniform temperature and consistency.

3.8   COMPACTION

A.   Use a small compactor or vibratory roller in addition to normal rolling at structures.

B.   Operate in a transverse direction next to the back wall and approach slab.

C.   Use aggressive rolling techniques to minimize risk of under-compacted PMOSA courses.

D.   Roll surface immediately after placement.

E.   Use at least one Pneumatic tire roller to aid in sealing the surface.

F.   Discontinue vibration if aggregate breakdown occurs or if bleeding occurs.

3.9   LIMITATIONS

A.   Do not place PMOSA on frozen base or subbase.

B.   Use a UDOT approved release agent for all equipment and hand tools used to mix, haul, and place the PMOSA. Contact the Engineer for approved product.

C.   Do not place PMOSA during adverse climatic conditions, such as precipitation, or when roadway surface is icy or wet.

D.   Place PMOSA from April 15, and October 15, and when the air temperature in the shade and the roadway surface temperature are above 50 degrees F.
1.   The Engineer determines if it is feasible to place PMOSA outside the above limits. Obtain written approval from the Engineer prior to paving from October 15, to April 15.

END OF SECTION

APPENDIX B

GARCO TESTING EXTRACTION RESULTS

GARCO TESTING LABORATORIES
ASPHALT CONTENT BY EXTRACTION, SIEVE ANALYSIS

Project:		Project Number:	
Client:	CIVCO Engineering	Sample Date:	01/11/11
Material:	Tar Sands	Sample Location:	
Source:		Sample Time:	
Lab Number:		Sampled by:	Customer
		Technician:	

Extraction of Asphalt from Bituminous Paving Mixtures - AASHTO T 164, ASTM D2172

Mass of Test Portion	1084.1	Mass of Extracted Aggregate	939.0
Filter Mass	19.9	Mass of Filter & Mineral Matter	21.5
Mass of Centrifuge Cup (0.01g)	264.05	Mass of Centrifuge Cup & Mineral Matter	266.91
Nass of Water in Test Portion	0.00	Mass of Mineral Matter	4.46
		Percent Asphalt Content	12.97

Sieve Analysis - AASHTO T 30, ASTM D 5444

Aggregate weight   939.0
Washed aggregate weight   886.0

Sieve Size		Weight Retained	Percent Retained	Percent Accumulated	Percent Passing	Target	Limits
25mm	1"				100		
19mm	3/4"				100		
12.5mm	1/2"				100		
9.5mm	3/8"				100		
4.75mm	#4	2.8	0.3	0.3	100		
2.36mm	#8	2.1	0.2	0.5	99		
1.18mm	#16	1.4	0.1	0.7	99		
0.600mm	#30	54.5	5.8	6.4	94		
0.300mm	#50	332.2	35.2	41.7	58		
0.150mm	#100	394.1	41.8	83.4	17		
0.075mm	#200	81.0	8.6	92.0	8.0		
-#200 Sieved out		11.2					
-#200 Washed out		53.0	Total -#200	68.7			
Total		879.3					

SG Recovered Oil AASHTO T228	0.9927	Bulk SG Extracted Agg AASHTO T84	2.539
		Bulk SSD SG Extracted Agg AASHTO T84	2.573
		Apparent SG Extracted Agg AASHTO T84	2.630
		% Absorption Extracted Agg AASHTO T84	1.358

APPENDIX C

BENDING BEAM RHEOMETER RESULTS PAGE

CANNON® Instrument Company, USA   3.21   03/26/2012 10:29:36 PM

Project :   BBR
Operator :   MCV
Specimen :   PTA11..24
Test Time : 10:20:23 PM
Test Date : 03/26/2012
File Name : PTA11..24
BBR ID :   U of U BBR

Target Temp (°C) : -24.0
Min. Temp (°C) :   -24.1
Max. Temp (°C) :   -23.9
Temp Cal Date :   03/20/2012
Soak Time (min) : 60.0
Beam Width (mm) : 12.58
Thickness (mm) :   6.14

Conf Test (GPa) :   210
Conf Date :   03/26/2012
Force Const (mN/bit) : 0.15
Defl Const (µm/bit) :   0.156
Cmpl (µm/N) :   7.75
Cal Date :   03/26/2012
Software Version :   BBRw 3.21

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	3595	0.01607	2.01e+004	2.01e+004	0.000	0.064
15.0	3594	0.01669	1.94e+004	1.92e+004	-1.03	0.075
30.0	3595	0.01824	1.77e+004	1.82e+004	2.82	0.087
60.0	3596	0.01869	1.73e+004	1.71e+004	-1.16	0.099
120.0	3596	0.02024	1.6e+004	1.59e+004	-0.625	0.111
240.0	3596	0.02226	1.45e+004	1.46e+004	0.690	0.122

A = 4.35   B = -0.0284   C = -0.0197   R² = 0.985975

Force (t=0.0s) =   29 mN   Deflection (t=0.0s) = 0.00000 mm
Force (t=0.5s) = 3346 mN   Deflection (t=0.5s) = 0.01397 mm

Max Force Deviation (t=0.5 - 5.0s) =   -249, +0 mN
Max Force Deviation (t=5.0 - 240.0s) =   -2, +2 mN

Average Force (t=0.5 - 240.0s) = 3595 mN
Maximum Force (t=0.5 - 240.0s) = 3597 mN
Minimum Force (t=0.5 - 240.0s) = 3346 mN

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