Exploring Different Forms of Base Stabilization

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Our nation’s roadways have experienced a growing demand over the past couple of decades. With decreasing funds and the need to provide the public with an efficient, safe, and cost effective roadway system, there has been a remarkable increase in the need to rehabilitate our existing pavements. When a flexible pavement has deteriorated to the point where rehabilitation or reconstruction is necessary, pavement engineers have traditionally used either the mill and overlay strategy or complete reconstruction. With the advances made on road construction equipment over the last two decades, there has been a growth in asphalt recycling and reclaiming as a technically and environmentally friendly way of rehabilitating the existing, failed pavements. An example of rehabilitation is base stabilization, or Full-Depth Reclamation. This research identified two mix designs for Portland cement base stabilization, three mix designs for asphalt emulsion base stabilization, and two mix designs for asphalt foam base stabilization. These mix designs are currently being synthesized to produce one final mix design for each technology. Preliminary testing indicated that the modified proctor and Superpave Gyratory Compactor can produce similar moisture density curves. In addition, increasing the water content and asphalt foam content of asphalt foam base stabilization mixture increased the compressive strength.

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16. Abstract

Our nation's roadways have experienced a growing demand over the past couple of decades. With decreasing funds and the need to provide the public with an efficient, safe, and cost effective roadway system, there has been a remarkable increase in the need to rehabilitate our existing pavements. When a flexible pavement has deteriorated to the point where rehabilitation or reconstruction is necessary, pavement engineers have traditionally used either the mill and overlay strategy or complete reconstruction. With the advances made on road construction equipment over the last two decades, there has been a growth in asphalt recycling and reclaiming as a technically and environmentally friendly way of rehabilitating the existing, failed pavements. An example of rehabilitation is base stabilization, or Full-Depth Reclamation. This research identified two mix designs for Portland cement base stabilization, three mix designs for asphalt emulsion base stabilization, and two mix designs for asphalt foam base stabilization. These mix designs are currently being synthesized to produce one final mix design for each technology. Preliminary testing indicated that the modified proctor and Superpave Gyratory Compactor can produce similar moisture density curves. In addition, increasing the water content and asphalt foam content of asphalt foam base stabilization mixture increased the compressive strength.

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1 PROJECT ABSTRACT

Our nation's roadways have experienced a growing demand over the past couple of decades. With decreasing funds and the need to provide the public with an efficient, safe, and cost effective roadway system, there has been a remarkable increase in the need to rehabilitate our existing pavements. When a flexible pavement has deteriorated to the point where rehabilitation or reconstruction is necessary, pavement engineers have traditionally used either the mill and overlay strategy or complete reconstruction. With the advances made on road construction equipment over the last two decades, there has been a growth in asphalt recycling and reclaiming as a technically and environmentally friendly way of rehabilitating the existing, failed pavements. An example of rehabilitation is base stabilization, or Full-Depth Reclamation. This research identified two mix designs for Portland cement base stabilization, three mix designs for asphalt emulsion base stabilization, and two mix designs for asphalt foam base stabilization. These mix designs are currently being synthesized to produce one final mix design for each technology. Preliminary testing indicated that the modified proctor and Superpave Gyratory Compactor can produce similar moisture density curves. In addition, increasing the water content and asphalt foam content of asphalt foam base stabilization mixture increased the compressive strength.

2 PROJECT OBJECTIVES

There were four objectives to this project:

1. Perform a thorough literature review investigating past experience with mix design of the three most common base stabilization techniques: Portland cement, asphalt emulsion, and asphalt foaming
2. Identify at least two roadways in need of stabilization in Arkansas and collect samples to explore previously found mix design procedures
3. Identify the most promising mix design procedure and write draft specifications for mix design procedures for Portland Cement, asphalt emulsion, and asphalt foaming base stabilization techniques
4. Produce laboratory samples for each base stabilization technique, using the proposed mix design specifications, and perform torture and cracking performance tests to examine the difference in behavior of the three techniques on our existing pavements.

Because the funding from MBTC was cut from $65,501 to $14,387, some changes were necessary in order to complete the work. The next four sections will describe the progress made on the four objectives, and the work that will need to be done in the future.

3 MIX DESIGN LITERATURE REVIEW OF THREE BASE STABILIZATIONTECHNIQUES

Sustainability has become a popular term recently in the field of engineering, especially in pavements (Alkins et al., 2008). The concepts behind sustainability, however, have been practiced in pavement design for over one hundred years. One of the central ideas of sustainability is, in fact, reducing the quantity of natural resources consumed during construction (ASCE, 2004). Within the field of bitumen pavements, both cold recycling and base stabilization, the roots of each developed in the early 1900s, rely almost exclusively on in-place materials (ARRA, 2001). These construction techniques reduce the quantity of virgin resources and the hauling of materials to and from job sites. Base stabilization of pavements, or Full-Depth Reclamation (FDR), recycles both bituminous layers as well as existing granular material beneath the bituminous layers. Base stabilization can solve surface distresses in addition to increasing structural capacity. With the ability to incorporate non-bituminous material, base stabilization can be utilized on thinner pavements.

There is a significant amount of literature that revolves around performance testing of base stabilized mixtures. Marshall stability (Ruckel et al., 1983), indirect tensile strength (Huffman, 1997), semi-circular bend tensile strength (Jenkins et al., 1999), monotonic shear triaxial (Jenkins et al., 2007), resilient modulus (Maurer et al., 2007), flexural beam (Fu et al., 2008), dynamic modulus (Diefenderfer and Apeagyei, 2011), and unconfined compressive strength (Thompson et al., 2009) have all been utilized in order to better understand material behavior. However, many of these reports do not state how the mix designs were performed; they simply discuss the testing results.

Several research groups have attempted to use existing mix design procedures for Hot Mix Asphalt in order to design base stabilization mixtures. Kearney and Huffman (1999) used both the Hveem and Marshall mix designs in order to produce base stabilized mixtures. Mallick et al. (2001, 2002) modified the Superpave mix design procedure in order to fabricate samples. Unfortunately, these mix designs were not originally developed for base stabilized mixtures, which often have higher levels of fines, soil-type material, and use asphalt emulsion, asphalt foam, or Portland cement as the stabilizing agent versus asphalt cement. Therefore, an overview of the most important requirements for base stabilization mix design was performed in order to understand which procedures were adequate for our use.

3.1 BASE STABILIZATION MIX DESIGN REQUIREMENTS

Base stabilization is a roadway recycling process in which the entire pavement and some of the underlying material is pulverized and treated with an additive to produce an improved, stabilized foundation for a future roadway. Through altering the mix proportions of aggregate, asphalt emulsion/asphalt foam/Portland cement and active filler it is possible to produce a mix that behaves similar to granular materials, cemented materials or Hot Mix Asphalt. There are two main failure mechanisms that that need to be taken into consideration in the mix design process.

Permanent deformation is the accumulated shear deformation with loading and is dependent on the material's shear properties and densification achieved. Resistance to permanent deformation is improved by:

- Improved aggregate angularity, shape, hardness and roughness
- Increased maximum particle size
- Improved compaction
- Reduced moisture content
- Addition of a limited amount of asphaltic material, usually under 3.5% to decrease rutting
- Addition of active filler, usually limited to a maximum of 1% to decrease brittleness.

The presence of water in base stabilized mixtures as well as the partially coated nature of the aggregate makes moisture susceptibility an important consideration in the evaluation of material performance. Moisture susceptibility is the damage caused by exposure of base stabilized mixtures to high moisture contents and pore-pressures, caused by traffic. This results in the loss of adhesion between the binding agent and the aggregate. Moisture resistance is enhanced by:

- Increased asphalt content, taking into consideration the cost implications and potential for permanent deformation.
- Addition of active filler, usually limited to 15% by mass of dry aggregate.
- Improved compaction
- Smooth continuous grading.

Through a literature review of numerous base stabilization mix designs, it was apparent that there is no single adopted mix design that could meet these criteria. However, seven mix designs were identified that addressed many of these issues. Two of these mix designs are for cement stabilized base, three for asphalt emulsion stabilized base, and two for asphalt foam stabilized bases. These seven mix designs are discussed in the following section.

3.2 COMPARISON OF SEVEN MIX DESIGNS

The mix design of base stabilization materials is particularly challenging due to the number and types of ingredients that comprise these materials. However, seven mix designs were specifically identified for the three types of base stabilization: two for cement, three for asphalt emulsion, and two for asphalt foam. The following sections break down these three types of mix designs and compare the pros and cons to each.

3.2.1 PORTLAND CEMENT BASE STABILIZATION

Two documents were found that provide straight forward mix designs practices for Portland cement base stabilization (Luhr et al., 2008; Wirtgen, 2010). Lehr et al. provided a mix design for the Portland Cement Association (PCA); from here on, this mix design will be referred to as the PCA cement. Wirtgen is a private company that produces reclaiming equipment. From here on, this mix design will be referred to as the Wirtgen cement.

Both of these methods first establish a material density relationship. The PCA cement procedure determines the compaction density through ASTM D558: Standard Test Method for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures. In short, the test determines the maximum dry density for the base stabilization mix, and the influence of moisture content on obtaining that density. Similarly, the Wirtgen cement procedure determines the optimal moisture content and maximum dry density through AASTHO T-180: Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop. At the end of the day, both of these methods are trying to determine the optimal material density at varying water contents. If the mix is too dry, the particles will not be able slide by each other (lubrication); if the mix is too wet, the water will push the particles away from each other. By establishing the optimal moisture content, the optimal conditions for compaction are found.

After the optimal moisture content is found, both the PCA cement and Wirtgen cement procedures require strength testing. Both procedures require moist curing for seven days so that the cement hydrates and hardens. The PCA cement method only requires Unconfined Compressive Strength (ASTM D1633: Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders), while the Wirtgen method requires both Unconfined Compressive Strength and Indirect Tensile Strength. Wirtgen has developed special test methods for these two tests that can be found in Wirtgen, 2010.

Overall, the principles behind the PCA cement and Wirtgen cement mix design procedures are essentially identical. Both call for finding the optimal moisture content, and both use the Unconfined Compressive Strength to categorize the mixture. Therefore, either mix design procedure can be used for cement base stabilization.

3.2.2 ASPHALT EMULSION BASE STABILIZATION

Three specific mix designs were chosen to potentially synthesize into a streamlined version. The most comprehensive of the three was found to be from the Asphalt Academy, 2009. This report is based off of an extensive study done in South Africa with the main method for compaction being the Bosch vibratory hammer. The report is very in depth and comprehensive. That being said, it is our belief that it would not be practical for a typical lab to have all of the necessary equipment to perform the tests that are stated. This report will be used in various ways as a reference but will not be followed specifically. Another of the mix designs that will be referenced was comprised by the North Carolina Department of Transportation (NCDOT), “Asphalt Emulsion Full Depth Reclaiming and Stabilization”. This mix design is based off of the compaction method using the Superpave Gyratory Compactor (SGC). Similarly, the third report, and the one that will be most closely followed, is the “Development of a Rational and

Practical Mix Design System for Full Depth Reclamation (FDR)" (Mallick, 2001). This report seems to encompass the full capabilities of a standard mix design lab that most DOT's would have. This report is very easy to follow and is laid out in a very uniform manner, which is one of the reasons that it will be most closely followed.

Asphalt Academy, South Africa

The mix design proposed by the Asphalt Academy in South Africa involves several steps and one or more series of tests, depending on the traffic levels and loads. The procedure always begins with preliminary testing of the in-place material to determine if it is suitable for treating with asphalt emulsion and, if not, the type of pre-treatment or blending required to make it suitable. The preliminary tests include standard laboratory tests to determine the grading curve, moisture, density relationships and Atterberg limits. If through the results of these tests, it is found that some form of pre-treatment is required, additional tests must be undertaken.

Level One mix design starts with the preparation of samples that will be used to make specimens required for all levels of mix design testing. 100mm diameter specimens (Marshal briquettes) are compacted and cured for Indirect Tensile Strength (ITS) testing. This level of the mix design is used to identify the preferred bitumen stabilizing agent, determine the optimum bitumen content, and identify the need for filler type and content. This level of testing is appropriate for lightly trafficked pavements, which will carry less than 3 million equivalent single axles (MESA). Level Two uses 150 mm diameter by 127 mm high specimens (Proctor specimens) manufactured using vibratory compaction, cured at equilibrium moisture content and tested for Indirect Tensile Strength to optimize the required bitumen content. This level is recommended for roads carrying 3 to 6 MESA. Level Three uses triaxial testing on 150 mm diameter by 300 mm high specimens for a higher level of confidence. This step is recommended for roads exceeding 6 MESA.

After the appropriate level has been chosen, based on expected traffic loads, the specimens must be cured before testing can begin. For Level One mix designs, the 100 mm diameter specimens are cured until they reach a constant mass, typically with moisture contents of less the 0.5%. Testing will follow after seventy two hours of curing at a constant temperature of 40°C without sealing the specimen. This is done to determine the $ITS_{(dry)}$ value. Half of the specimens are then soaked for twenty four hours before testing to determine the $ITS_{(wet)}$ value. The results from this test are used to determine the moisture susceptibility of the mix. The curing of the Level Two and Level Three mix designs typically produces moisture contents of 43 to 50% of optimum moisture content (OMC), which represents the long-term equilibrium moisture content of the material in the field. Initially, unsealed specimens are placed in a draft oven and cured for twenty six hours at 30 °C to allow the moisture content to reduce. Afterward, they are individually sealed in loose-fitting plastic bags and cured for another forty-eight hours at 40 °C. Before the specimens are tested, they should be allowed to cool down to the required test temperature. Interpretation of the results is included in the original document but will not be discussed here.

Specified grading curves are suggested with the main concern being the presence of fines. Emulsion coats the larger aggregate particles, so a minimum fines content of 2% is sufficient. If, after investigation, the in-place material is found to be lacking in certain sieve sizes, aggregates can be blended to improve the grading.

NCDOT

The mix design proposed by NCDOT differs from the previous mix design by using the SGC as the primary compaction method as opposed to the vibratory hammer. The mix design distinguishes the criteria for the mix into two categories: Base stabilization Type 1 or Base stabilization Type 2. The two tables below show the differences in the two.

Table 1 – Base stabilization Type 1: For mixtures containing < 8 percent passing No. 200

150 mm diameter specimens shall be prepared in a Superpave gyratory compactor	
Property	Criteria
Superpave gyratory compaction, 1.25° angle, 600 kPa, gyrations	30
Short-term strength test, 1 hour - modified cohesiometer, ASTM D 1560-92 (Part 13), g/25 mm of width	175 min
Indirect tensile strength (ITS), ASTM D 4867 Part 8.11.1, 25°C, psi	40 min
Conditioned (ITS), ASTM D 4867, psi	25 min
Resilient modulus, ASTM D 4231, 25°C, psi x 1000	150 min
Thermal cracking (IDT), AASHTO T-322	

Table 2 – Base stabilization Type 2: For mixtures containing ≥ 8 percent passing No. 200 or for all granular mixtures

150 mm diameter specimens shall be prepared in a Superpave gyratory compactor	
Property	Criteria
Superpave gyratory compaction, 1.25° angle, 600 kPa, gyrations	30
Short-term strength test, 1 hour - modified cohesiometer, ASTM D 1560-92 (Part 13), g/25 mm of width	150 min
Indirect tensile strength (ITS), ASTM D 4867 Part 8.11.1, 25°C, psi	35 min
Conditioned (ITS), ASTM D 4867, psi	20 min
Resilient modulus, ASTM D 4231, 25°C, psi x 1000	120 min
Thermal cracking (IDT), AASHTO T-322	

Prior to mixing the samples with water and emulsion, they shall have a weight that will produce 70 to 80 mm tall compacted specimens. Four emulsion contents should be chosen that will encompass the design emulsion content. Samples are made at each emulsion content to obtain a wider range of data to help narrow the optimum emulsion content. Once the specimens have been compacted, they are subjected to the tests listed above in the tables.

<u>Mallick, 2001</u>

The objectives of this report are to develop a rational mix design for base stabilization and evaluate different additives used in base stabilization. Specifically, the objectives are:

1. Develop a mix design method using the Superpave gyratory compactor.
    a. Develop guidelines for the use of Superpave gyratory compactor for preparation of samples for mix design.
    b. Determine proper compactive effort in terms of gyration number for selection of optimum additive content.
2. Determine proper curing procedure before compaction, after compaction and before testing of mixes during laboratory mix design.

The mold that is to be used in this study contains several holes around the mold, through which water can escape during compaction. This is done because when a mix is compacted in the field, water is allowed to escaped, and, therefore, the mix loses moisture as and when it is compacted. With a closed mold this is not the case, which is why the newly designed mold is used.

Before compaction with the SGC, the mixes are allowed to cure for 45 minutes at 40°C. Once the samples have been cured, they are compacted to 75 gyrations. The samples are then tested for bulk specific gravity using the CoreLok method. Samples are transferred to an oven maintained at 40°C for post compaction curing. Next, the samples are taken out every 24 hours and tested for mass and resilient modulus. At the end of 10 day curing period, the samples are tested for resilient modulus and indirect tensile strength. When the dry density versus total fluid content is plotted, it indicates that the emulsion and the pre-wet water actually work together as a fluid. This is used to determine the recommended emulsion content.

The overall work plan of this report consisted of development of a mix design method using the SGC, construction of test section, evaluation of in-place materials, refinement of mix design and testing of in-place materials nine months after construction of tests sections.

This procedure will be reproduced as closely as possible when actual projects are visited in summer 2012. Then, after the data is analyzed, it will be synthesized into a similar mix design. This new mix design will encompass aspects from all three of the designs that were reviewed and will be open for review and alteration when new information is presented.

Summary of Asphalt Emulsion

As can be seen in the previous sections, the three mix designs for asphalt emulsion are quite varied and quite complicated, depending on traffic level, material, and various other factors. A further complication is that the South African design is driven from a soil mechanics background, while the NCDOT and Mallick mix designs are driven from a Hot Mix Asphalt background. The work on developing an optimal mix design for asphalt emulsions is still ongoing, as there are many details to be worked out.

3.2.3 ASPHLAT FOAM BASE STABILIZATION

Two documents were found that provide straight forward mix design practices for asphalt foam base stabilization (Asphalt Academy, 2009; Wirtgen, 2010). The Asphalt Academy mix design was developed in South Africa; from here on, this mix design will be referred to as the South Africa foam. Wirtgen is a private company that produces reclaiming equipment; from here on, this mix design will be referred to as the Wirtgen foam.

The first step in both mix designs is identifying the active filler requirements. The active filler (either hydrated lime or cement) assists in dispersing the asphalt foam. For the South Africa foam design, if the Plasticity Index (PI) is greater than 10, the material must be pre-treated with either cement (1% maximum) or lime (1.5% maximum). In the Wirtgen foam design, if the PI is less than 10, 1% of active filler should be added, whereas if the PI is greater than 10, 2% of the active filler should be added.

For both the South African foam design and the Wirtgen foam design, both procedures call for finding the optimal moisture content. This is similar to the Portland cement and asphalt emulsion mix designs, because the workability and compaction of the mix is essential when placing. However, an important difference between the asphalt emulsion and asphalt foam designs is that the water from the asphalt emulsion counts toward the moisture content of the optimal moisture content, whereas the water in the asphalt foam does not.

The next step of the foamed mix design, for both procedures, is the determination of the optimal foam and optimal water content to produce the foam (as opposed to the water to determine the optimal moisture content). This is referred to as the “Optimal Foamant Water Content.” Figure 1 is taken from the South African foam design manual, but an identical figure can be found in the Wirtgen foam design manual.

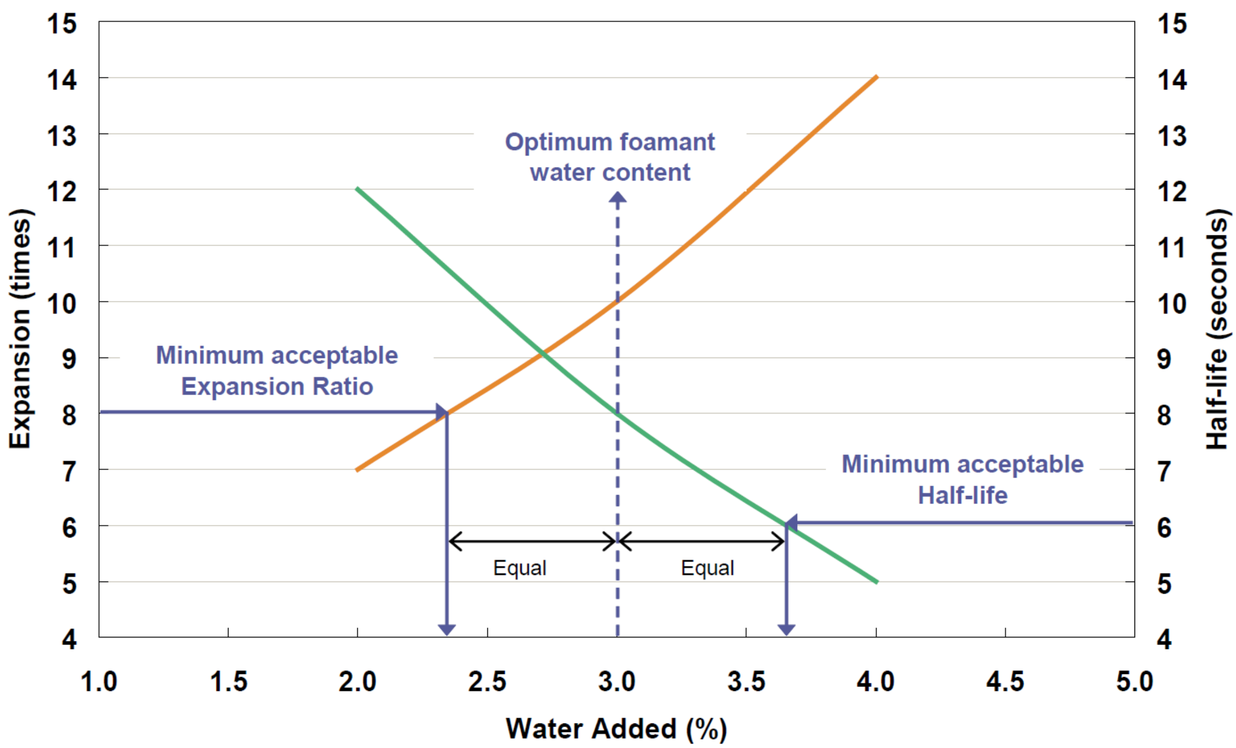

Figure 1 – Optimal foamant water content (from Asphalt Academy, 2009)

The two curves in Figure 1 change based on the type of asphalt cement that is being foamed. However, a minimum expansion ratio of eight times and a minimal half-life of six seconds for both mix designs. It is important to note that in each foam procedure, time is important as the foamed asphalt “collapses” rapidly after the foaming process. If the foamed asphalt is not immediately mixed with the aggregate, the foam will collapse and not coat and adhere to the aggregate properly.

The South African foam procedure closely follows the asphalt emulsion procedure described in the previous section, with three levels of mix design put through a slew of tests. The Wirtgen foam procedure consists of making sets of samples at four different foamed asphalt contents and running Indirect Tensile Strength tests both in the wet and the dry condition. The South African foam procedure is much more complex and also involves a higher level of effort.

3.3 MIX DESIGN SUMMARY

Overall, seven mix design procedures were identified for the Portland cement, asphalt emulsion, and asphalt foam base stabilization techniques. The three different materials require very different approaches to material selection. Just identifying these seven procedures required an immense amount of literature review and discussion with industry. Work will continue to move forward on all three mix designs, but at this point, an optimal mix design for each technology has not been identified.

4 ARKANSAS ROADWAY SELECTION

The catalyst for this project was the condition of roadways in the Fayetteville Shale area. The state roadways in this area traditionally have a relatively thin pavement structure, designed for mostly car or light truck traffic. However, the recent discovery of natural gas has ushered in a new level of heavy traffic. Figure 2 shows an example of one of the drilling trucks that is not uncommon on the roadway.

Figure 2 – Heavy construction traffic on a Fayetteville Shale area state highway

Generally, base stabilization is performed by milling the pavement using a reclaiming machine. If performed correctly, this creates a blended material of the asphalt pavement, the base course, and occasionally some of the subbase as well. Figure 3 is a schematic of the reclaiming processes using the foaming technology.

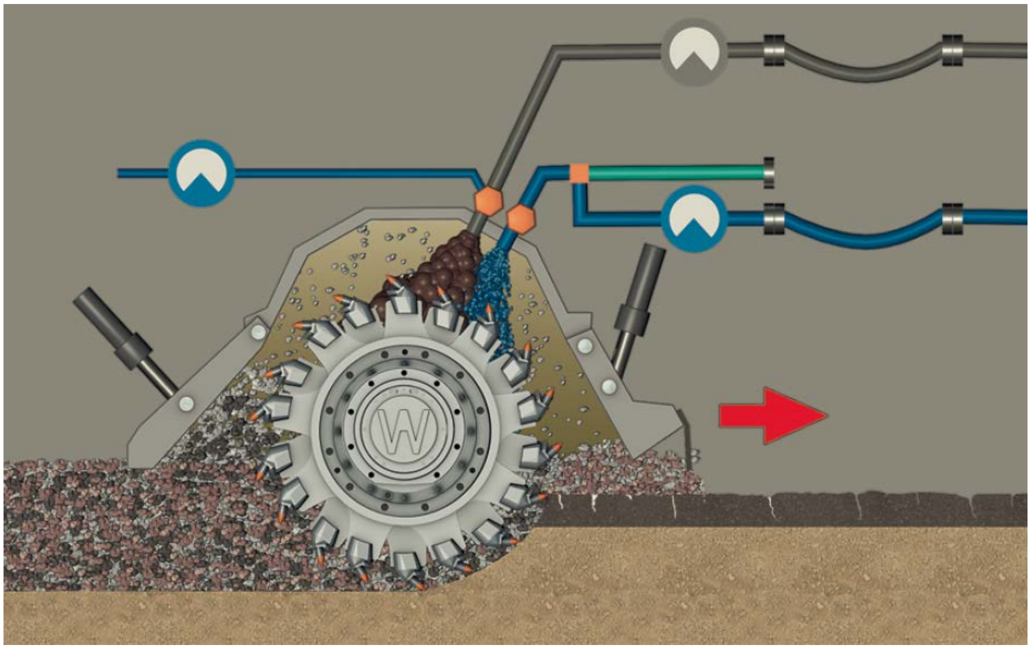

Figure 3 – Reclaiming process for base stabilization using the foaming technology (from Wirtgen, 2010)

In Figure 3, the asphalt cement is being combined with the asphalt cement to make the asphalt foam, while additional water is being added to achieve optimal moisture content. Asphalt emulsion can be added instead of the asphalt foam, or Portland cement can be placed on the roadway surface immediately ahead of the reclaiming machine. In all cases, the stabilizing agent is added to relatively finely graded, blended material.

In October, 2011, the PI for this project contacted Arkansas State Highway Transportation Department in order to find several roads that could be sampled and used to verify the seven mix designs discussed above. After two and a half months, a single roadway was finally identified, Arkansas State Highway 95, just outside of Clinton, AR. The roadway was undergoing remove and replace of individual sections that were significantly damaged. Figure 4 shows how a backhoe was used to remove the asphalt concrete, along with about six inches of material underneath.

Figure 4 – Material removal from AR95

While the method of remove and replace is useful for patching, it unfortunately, is not representative of how a milling head can break down and mix the pavement material during a true base stabilization job. Therefore, the samples in the lab are in need of more post-processing, as seen in Figure 5.

Figure 5 – The condition of pavement samples in the lab

In order to crush the roadway samples, a rock crusher is being purchased that will be able to break the samples into sizes 1/8" to 3/4" size. Until this crusher arrives in the laboratory, however, the samples can't be used in a base stabilization mix design. Therefore, material from a local aggregate quarry (Sharps Quarry) was sampled and blended into a "representative" base stabilization mix. This was accomplished by using a blend of 1/2" limestone chip, base material (Class 7 aggregate), and Recycle B Recycled Asphalt Pavement (RAP). Table 3 shows the gradation used for preliminary testing of a base stabilization mix design.

Table 3 – Gradation used for base stabilization mix design

Percent	10	65	25	100	Control Points	
Sieve Size (mm)	1/2 LM chip	Class 7	RAP	Job Mix	Min	Max
50	100	100	100	100	100	100
37.5	100	100	100	100	87	100
25	100	70	100	82	77	100
19	100	60	100	76	66	99
12.5	100	50	100	70	57	87
9.5	83	40	96	61.1	49	74
4.75	6	35	71	42.9	35	56
2.36	2	30	53	34.1	25	42
1.18	2	25	41	27.5	18	33
0.6	2	20	33	22.1	14	27
0.3	2	15	26	17	10	21
0.15	2	10	18	11.6	7	16
0.075	1.7	5	11.7	6.68	4	9

In order to fall within the control points, 10% of the 1/2" limestone chip, 60% of the Class 7 base material, and 30% of the Recycle B Recycled Asphalt Pavement (RAP) was used. This blend allowed the job mix gradation to fall within control points established for base stabilization by the Asphalt Academy (2009). While using aggregate from a quarry is not representative of what will be found in the field, it is significantly easier to manage gradation and material quantity with a steady source of material. Therefore, in order to take the first step of base stabilization research, quarry material will be used. The final gradation is shown in Figure 6.

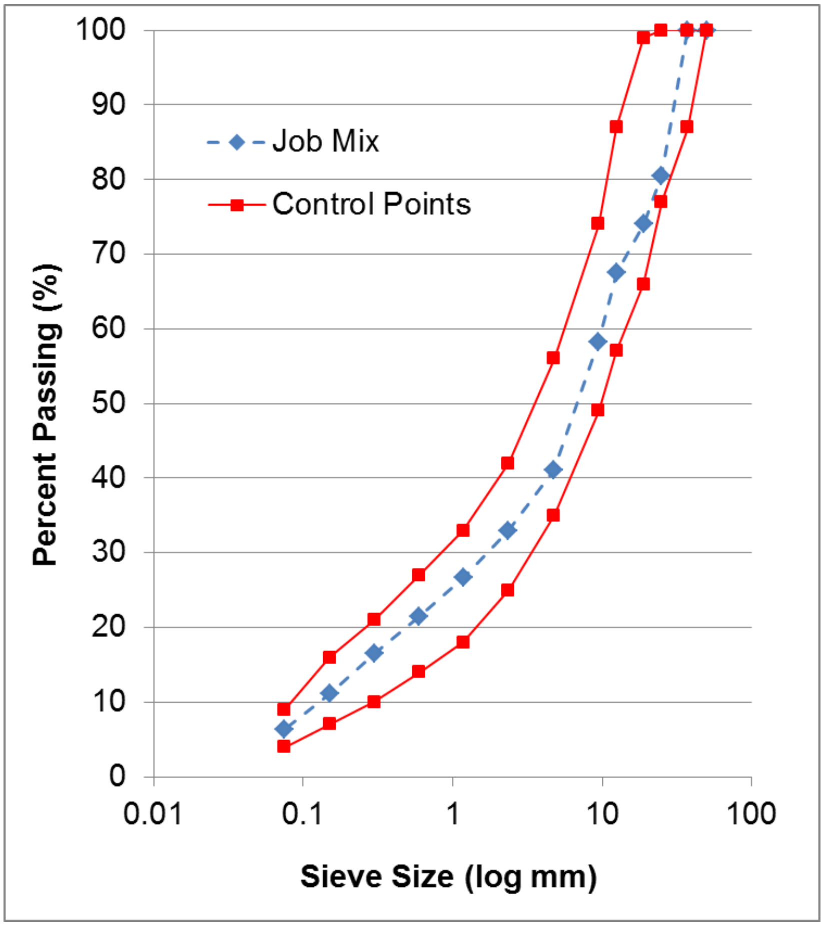

Figure 6 – Final base stabilization gradation for laboratory investigations

With aggregate obtained from a quarry, materials were available to continue the research project, which was to identify the most promising mix design procedure.

5 FINAL MIX DESIGN PROCEDURE

As discussed above, three different base stabilization techniques are available: Portland cement, asphalt emulsion, and asphalt foam. For this project, the Portland cement procedure was put on hold, as Arkansas State Highway Transportation Department was already pursuing mix design procedures through TRC-1201. The asphalt emulsion mix design procedure was also put on hold, as the asphalt emulsion mill ordered in December, 2011, has still not arrived as of July 24, 2012. Therefore, the technology pursued was the asphalt foam. A Wirtgen WLM 30 dual pug mill shaft mixer and Wirtgen WLB 10 S foaming machine was ordered and utilized in order to produce samples. Figure 7 is a picture of the pieces of Wirtgen equipment.

Figure 7 – Wirtgen WLM 30 mixer (left) and Wirtgen WLB 10 S foaming machine (right)

Since Wirtgen equipment was being utilized, the Wirtgen foam mix design procedure was used for the rest of the research project. This procedure can be found online at (http://www.wirtgen.de/) in the Wirtgen Cold Recycling Technology manual.

6 PERFORMANCE TESTING OF BASE STABLIZED MIXTURES

The aggregate used was described in section four of the report. The asphalt cement used for the foaming process was a PG 64-22 provided by Lyon Oil. This type of asphalt cement is commonly used in Arkansas.

The water content in the foamed asphalt was determined using the expansion ratio and the half-life of the foam according to the instructions on the Wirtgen foaming machine. The midpoint water content between the minimum expansion ratio and the minimum half-life is taken as the water content. To obtain this value, a 500 gram foamed sample is sprayed into a bucket with a measuring rod specifically designed for this test. The measuring device initially reads the total expansion, and a second person records the time from the initial expansion until the sample volume is at half of the original value. This water content varies with the type of binder used. This process is illustrated in Figure 1. Because there were multiple foam contents explored in this study, there were also multiple water contents.

After mixing the samples, a Superpave Gyratory Compactor (SGC) was used based on recommendations from Mallick, 2001 at an N_{des} of 75 gyrations. The use of an SGC causes much of the water to be “squeezed” or drained out of the sample. This moisture reduction causes the curing time to be very short. A time of one week for emulsion samples was recommended by Mallick, 2001 as being more than enough for the sample to fully cure. Generally foamed asphalt does not require curing, but it was believed that the high water contents used in the samples would have different strength characteristics over time. This same amount is used in this experiment for foamed asphalt samples because it was conducive to the research schedule.

6.1 *DETERMINATION OF THE OPTIMAL WATER CONTENT*

A modified proctor test (AASHTO T-180) was conducted using method C. According to instruction, only on material passing a 19 mm sieve was used. This required a large amount of material to be sieved. A box sieve was used to separate material needed, and each material was oven dried for 18 hours at 300F and then allowed to cool for approximately two hours. When drying the RAP at these temperatures, there was a concern that the binder in the sample would be altered. The same dried material was used for both samples, so even if there was an alteration through drying, it was consistent for both testing methods. In the future, material with existing asphalt cement, such as RAP, should not be dried at such high temperatures. The materials were then weighed as the proportion of the total mix design, and then they were sieved. The material which passed the sieve was mixed together, creating the same effect as if the whole sample was sieved together. A pugmill mixer was used to mix the sample. All material used in the compaction samples was divided and weighed out using an aggregate splitter to ensure that the gradation would be uniform between each sample and representative of the calculated gradation.

A previous standard proctor test done on similar material was conducted and the optimum moisture content of material passing a 4.75 mm sieve was determined to be 3.5%. The operator of the Wirtgen foaming machine estimated the optimum moisture content to be approximately 3%. The original water contents which were intended to be tested were 1.5%, 2.5%, 3.5%, 4.5% and 5.5%. Upon testing, it seemed clear that the water content of the material with the aggregate passing a 19 mm sieve, but not a 4.75 mm sieve, was higher than originally estimated. An adjustment was made during testing, and target water contents of 1.5%, 2.5%, 3.5%, 4.5%, 5.5%, 7.5%, and 9.5% were tested in compaction. When the target water contents samples of 9.5% and 5.5% were tested, the actual water contents measured were 7% and 16.5% respectively. These numbers were not used due to this inaccuracy.

The Asphalt Academy (2009) report recommended adding the optimum moisture content to the material during mixing. A potential problem was that the moisture content was calculated using only the weight and properties of the fine material with no information on the adsorption of the coarse aggregate. The coarse aggregates were assumed to have similar properties to fine aggregates tested. This assumption was utilized in the experiment, but further research should be conducted to judge if the optimum water content should be adjusted by the percent of aggregate caught on a 19 mm sieve.

The same material described for the modified proctor test was tested in compaction at different moisture contents with a slotted SGC. The moisture contents tested were in a similar range as the proctor test, but with more uniform spacing. The contents used were mixed in a pugmill mixer with the water content added after the oven dried material was well blended. The mixture was then blended for 60 seconds so the water would be uniformly distributed. This time was recommended during training for mixing samples with both water and foamed asphalt added, so it was assumed that the time would be adequate for only water. Every sample was weighed with water added, and exactly 5000 grams was measured for each sample. The SGC records the final sample height at 75 gyrations. Because the molds all have a fixed cross section and the height is recorded by the machine, the wet density was also easy to calculate. The dry density was found by using the following equation:

$$Ddry = m \times \left(\frac{D}{2}\right) \pi \times \quad \times (1 - w\%) \times .0022 \qquad \text{Equation 1}$$

where: D=Diameter in cm^2 (15 for an SGC)

h=Height in cm (digitally output by the SGC after test)

m=sample weight in grams (weighed at exactly 5000 g)

w%=water content as a percent.

The compaction results of the proctor curve are shown in Figure 8 and the results of the SGC are shown in Figure 9.

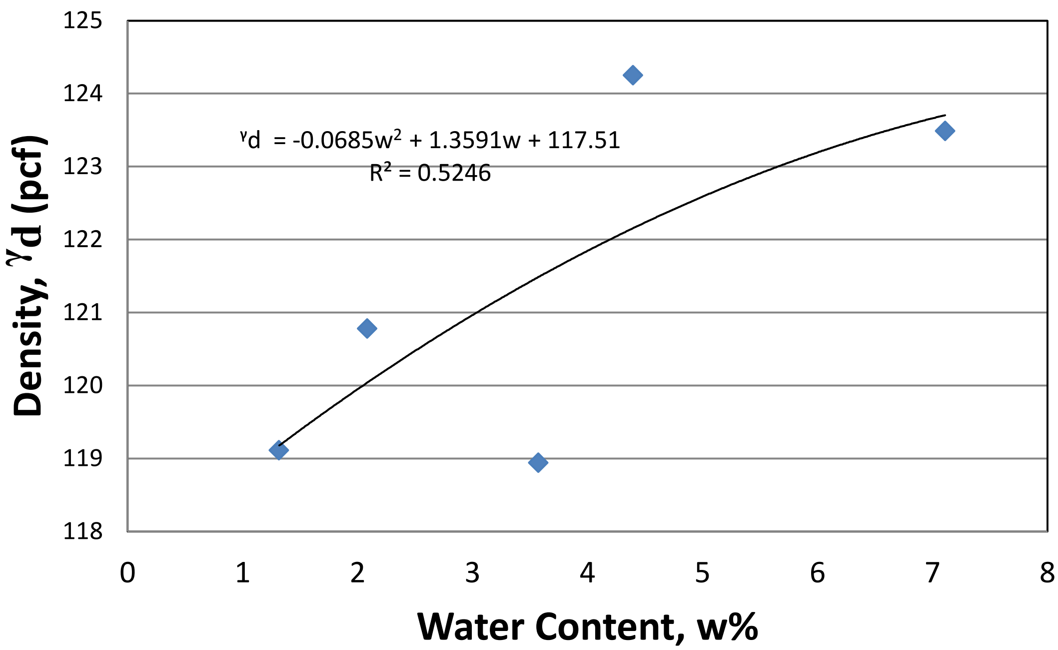

Figure 8 - Results of a modified proctor curve

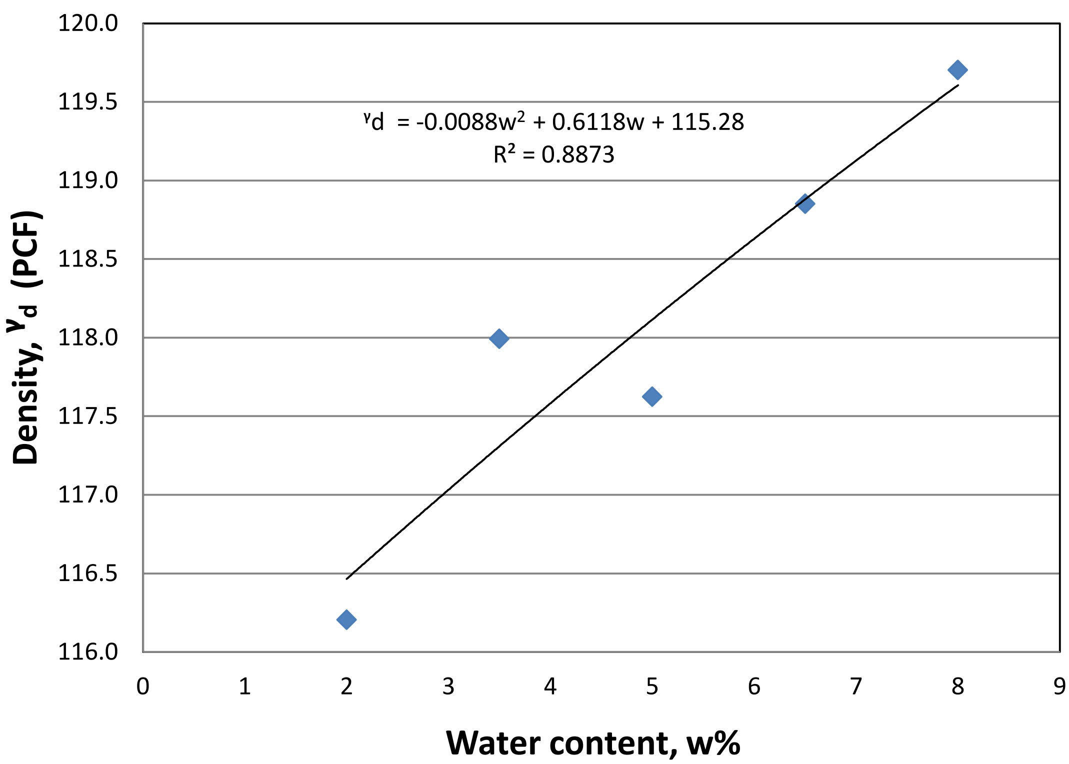

Figure 9 - Results of compaction in the SGC at different water contents

As is shown in these graphs, the results of the proctor curve and the SGC obtained similar results in relating compaction to moisture content. Both continue to increase until close to 7.5% water content. This was unexpected because previous testing of the material passing a 4.75 mm sieve and previous experience had indicated the OMC to be in the range of 3% to 4%. This is most likely due to the adsorption of the course aggregate. More testing must be done at higher moisture contents to observe the data at optimum moisture contents.

The densities recorded through the slotted gyratory compactor were lower than the densities recorded from a modified proctor test. This is reasonable because a modified proctor delivers more energy to the material than the slotted gyratory compactor.

The trends of these two graphs are very similar. The results of the SGC had a much higher R^2 value, which is most likely because the compaction process in an SGC is more automated and simpler than a modified proctor test. Therefore, the SGC compaction has less room for human error, and it can be accurately conducted with less training or experience. The use of a gyratory compactor will, therefore, also increase the repeatability of the test because the results are less dependent on the person.

6.2 *COMPRESSION TEST*

An experimental plan was developed in order to observe the effects of water content and binder content on the compaction characteristics of the asphalt foam base stabilized material and the compressive strength. The materials used for the design mix were oven dried for 24 hours in order to determine the water content in each. The materials were assumed to have uniform water content, and the material used in the mix was adjusted for the moisture weight assumed in each. Eleven samples were created at a weight of 15 kg. A splitter was used to ensure a uniform gradation in each of the samples.

The samples were made using a laboratory scale foaming machine WLB 10 S and a pug mill mixer WLM 30. The amount of water and binder added was calculated by weight. After the samples were mixed, three samples were weighed at 5 kg each. The time between mixing and compaction varied from approximately 10 minutes to an hour and a half. This time difference is a result of the gyratory compactor being much slower than the pug mill mixer, and three samples were made in the gyratory compactor for every one sample made in the pug mill mixer.

The dry density of each sample was calculated using Equation 1. These results are shown in Figure 10. Each sample from the gyratory compactor was tested in compression by standards outlined in CIP 35 (National Ready Mixed Concrete Association, 2003) in a Forney press. There were modifications which had to be made in order to test base stabilization samples instead of concrete. The first change was that tests falling below the 500 PSI range were not to be used. Since the maximum strength was below 200 PSI, this was unreasonable. Another modification made at the suggestion of a laboratory technician was that the neoprene pad and sulfur caps not be used in testing. This was also due to the difference of the material being tested. It was assumed that the samples were 150 mm in diameter because this was the mold size used in the experiment.

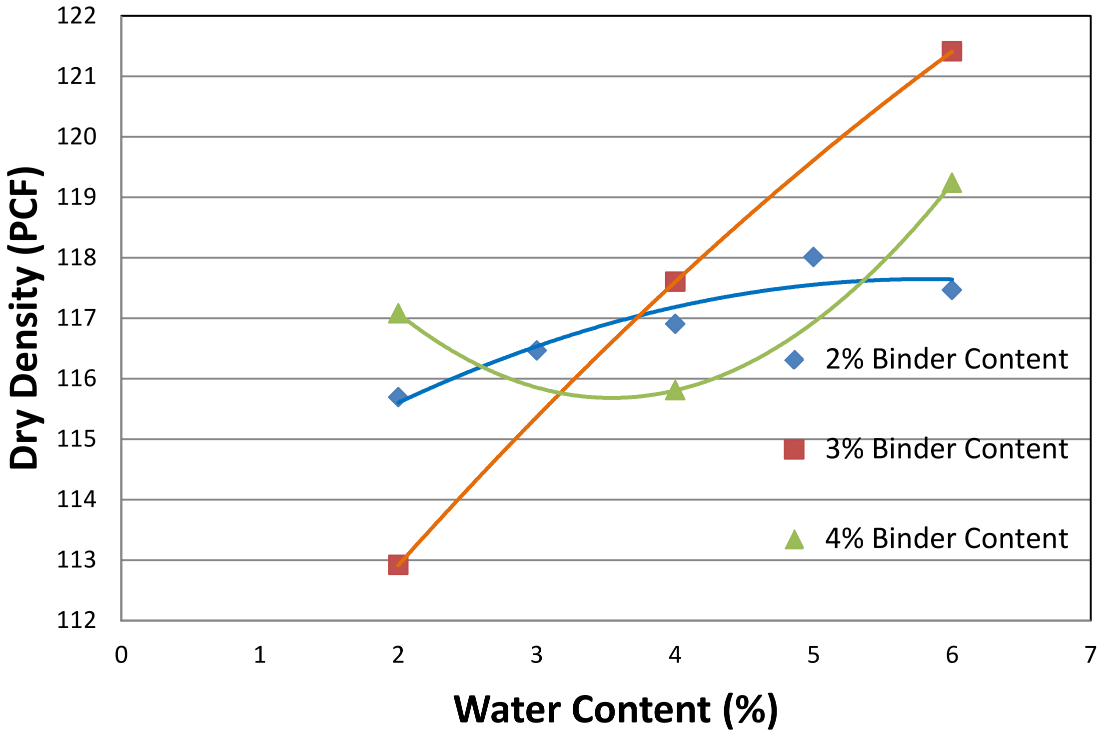

Figure 10 - Dry densities obtained using different water content and binder content

The samples were allowed to cure for a week before being tested. Some of the samples were damaged during extrusion, so the numbers which were gathered for these samples were slightly lower. It was common that the corner of a sample had fallen off. These damaged samples were noted on the data, but still tested with the exception of the sample compacted at 2% water content and 2% binder content. This sample could not support itself after being compacted and was damaged too badly to be used. There is a need to discover a way to successfully extract a base stabilization sample from a mold without damaging the sample. The ultimate compressive strength at failure was recorded and compared with the density of the sample and the water content. The results are shown below in Figure 11 and Figure 12.

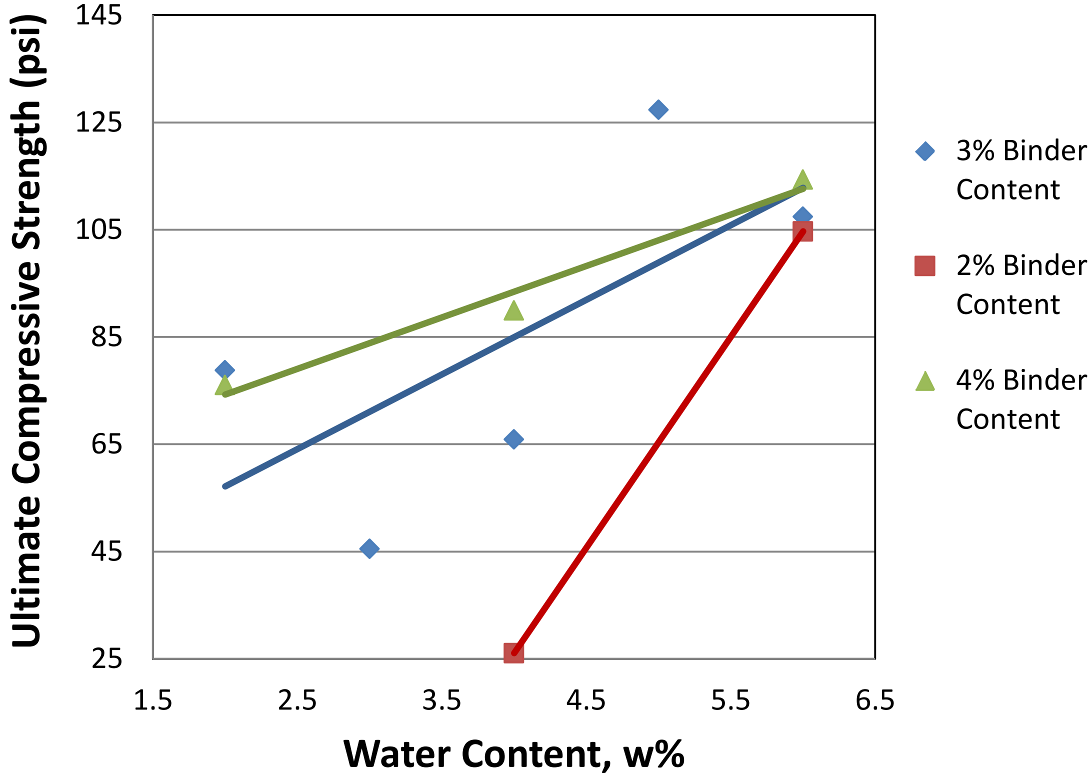

Figure 11 - Water content and compressive strength

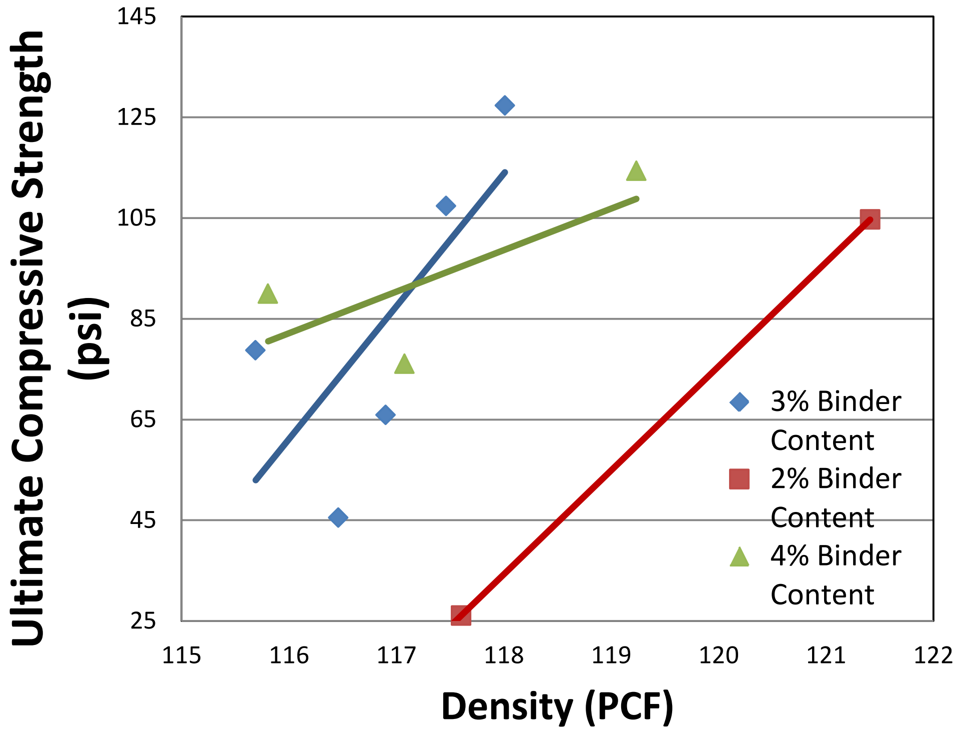

Figure 12 – Density and Compressive strength

These results are not in a very tight line. This is likely due to some of the samples being damaged in extrusion. The general trends are all consistent. They show that higher water contents will produce both higher density and higher compressive strength. If a sample has a higher dry density, it implies that there are fewer voids than a sample of the same material with a lower dry density. These voids will create higher internal stress concentrations in the samples, causing it to fail at lower compressive force. Higher binder contents will also increase compressive strength. Binder is the stabilizing agent used in base stabilization, so it follows that higher binder content will increase cohesion and compressive strength.

7 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Base stabilization is becoming a more popular method of pavement rehabilitation as it uses in-place material to build up the pavement structure. This allows for a sustainable method of increasing a pavement's structural capacity while minimizing cost and environmental impact. However, there is no set mix design procedure for base stabilization, whether using Portland cement, asphalt emulsion, or asphalt foam as the stabilizing agent. After performing a thorough literature review, this project looked to identify the most promising mix design procedures for these three base stabilization techniques and attempt to build final mix design procedures based on the information contained in existing mix design procedures. From the literature review, it was determined that seven mix designs total (two for Portland cement, three for asphalt emulsion, and two for asphalt foam), will provide the foundation for future research to develop and finalize the mix designs for each technique. Already, one undergraduate honors student is working on developing an optimal mix design for asphalt foam and one graduate student is working on synthesizing the three asphalt emulsion mix design procedures. However, there is much more work to be done, which was not possible within the modified budget of this proposal.

Samples were obtained from an Arkansas highway in the Fayetteville shale area, which is experiencing severe deterioration of its highway network due to the large volume and size of trucks carrying equipment and supplies for natural gas drilling. Unfortunately, these samples were not obtained using a milled process, so they were not properly processed for utilizing in a mix design procedure. Therefore, virgin materials from a local quarry were obtained in order to mimic a base stabilization job. While it is recognized that this is an idealistic method of evaluating materials, it will be used as a launching point for the more complicated situation where field materials are used.

Finally, to understand the performance properties of base stabilized materials, an asphalt foam mix design was used to produce samples in the laboratory with the material obtained from the aggregate quarry. Since base stabilization is often constructed by pavement contractors, who are more familiar with Superpave specifications versus soil specifications, moisture density curves were produced from both a modified Proctor mold and the Superpave Gyratory Compactor. The two methods obtained similar density curves, but the Superpave samples had slightly lower densities. In addition to the moisture density curves, a compression test was also performed on multiple asphalt binder contents and water contents. Overall, higher water contents and higher binder contents produced higher compressive strengths.

Base stabilization is an effective way to increase the structural capacity of a roadway. From this initial research, seven mix designs were obtained for Portland cement, asphalt emulsion, and asphalt foam technologies. Future research will condense these seven mix designs into three mix designs, one for each technology. In addition, further performance testing will be done on base stabilized mixtures. Finally, field samples that are able to be tested in the laboratory must be obtained in order to validate the mix design procedures, to ensure that they are compatible with actual field material, versus virgin material from an aggregate quarry.

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