Constructing and teaching a new asphalt laboratory for the engineering department at the University of Tennessee at Martin

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Abstract – Exposing undergraduate civil engineering students in a general engineering program to the hands-on pavement design experience is of great importance. This paper presents the work done to build and teach a new asphalt laboratory course for the engineering department at The University of Tennessee at Martin. The asphalt laboratory is part of a newly developed upper division course for undergraduate students titled "Pavement design and analysis". The content of the paper describes all the incorporated work including a description of pavement design methods and experiments chosen, purchasing the necessary equipment and installing them, teaching objectives and goals, performing the laboratory experiments, field work activities, and final assessment. The developed asphalt laboratory in conjunction with the pavement design and analysis course introduced students to the theory, laboratory procedure, and field work of the pavement design and construction.

Keywords: Asphalt, Laboratory, Equipment, Pavement, Design

INTRODUCTION

Building and constructing a new civil engineering laboratory is a challenging task and requires a lot of work. At the same time, exposing undergraduate civil engineering students in a general engineering program to the hands-on pavement design experience is of great importance. Pavement design and analysis is a newly developed civil engineering upper division undergraduate course offered at the department of engineering at the University of Tennessee at Martin. This course is a four- credit hour consisting of a three-hour lecture and a three-hour laboratory. The primary objective of the laboratory work is to introduce different methods required to design hot mix asphalt pavements to the civil engineering students.

Pavements are mainly two types: (1) Rigid pavement and (2) Flexible pavement. Pavements –whether rigid or flexible- consist of aggregate and a binder or a cementing element to bond the aggregates together. Most of the pavement structures in the state of Tennessee are built using flexible material and approximately 94% of the pavements in the United States are of flexible pavements [Huang 3]. The laboratory section of the course focuses on flexible pavement where "asphalt" is the binder used. There are two major design methods for Hot Mix Asphalt (HMA): (1) Marshall mix design and (2) Superpave mix design. Marshall mix design method is the classical and older method for the HMA design and differs from the later method (Superpave) in the compaction simulation of the materials, the size of the specimens prepared, and in including climatic and traffic variables in the design process [Roberts 3]. Both design methods share the basis of volumetric relationship needed for the optimum material design.

Challenges for building a new laboratory are numerous such as allocating/creating a budget for equipping the laboratory and finding a proper space within the building to locate the new facility. The intent of this paper is to share the experience of developing and teaching an asphalt laboratory course including laying out the laboratory, equipping the lab, developing procedure for laboratory experiments, and assessing the laboratory outcomes.

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COURSE OBJECTIVES

The pavement design and analysis course is an undergraduate-level course. The course covers design principles of highway pavements, flexible pavement materials testing and mix design, Traffic load analysis, pavement stresses and strains, and thickness design of asphalt and concrete pavements. This course is a four- credit hour consisting of a 3-hour lecture and a 3-hour laboratory. The laboratory section of the course is aimed to expose students to the principals of HMA material design using the Marshall and Superpave mix design methods. The grading system is based on two midterm exams, and a two-hour comprehensive final exam with a total of 65 percent of the final grade. Homework counts for 10 percent of the grade and Laboratory work and reports for the remaining 25 percent.

EQUIPMENT AND SPACE

Constructing the asphalt laboratory required the purchase of equipment and all the necessary tools to run the tests. A budget was allocated for this purpose from the department of engineering along with support from the state of Tennessee Architect and Engineering Licensing Board, as well as from Tennessee Department of Transportation (TDOT). The laboratory space was established within the department of engineering laboratory facilities ground floor by utilizing a well ventilated room. Renovations were required in order to achieve a proper layout of the laboratory. Both the Marshall mix design method and Superpave mix design method utilize some common equipment needed to weigh, heat, and mix the aggregate and asphalt. Figure 1 demonstrates the types and shapes of equipments used. The balance has a capacity of 12,000 grams and a pan size of (28 x 35.6) cm to meet the needs of the mix design procedure and is shown in Figure 1-a. Heating the material is a crucial step in the HMA mix design process and it is a requirement to heat both the aggregate and the asphalt to a certain mixing and compaction temperature that can reach up to 165° C. All mixing tools, bowls, and molds have to be heated as well to maintain optimum temperature. Two bench ovens were purchased similar to the one shown in Figure 1-b. A 20 quart Table mixer was also required to thoroughly blend and mix the aggregate with asphalt before preparing specimens, and can be seen in Figure 1-c.

(a) (b) (c)

Figure 1 Equipment needed to weigh, heat, and mix the HMA material: (a) balance, (b) bench oven, and (c) mixer

The volumetric properties and material proportioning play a great role in both mix design procedures. One critical property that has to be measured is the specific gravity for the loose (un-compacted) mixed materials. This is called the “Rice test” and is considered the maximum specific gravity for the mix. To run such a test, a pycnometer, vacuum pump, vibration Table, and a pressure gage is needed to simulate an air-free loose mix condition as seen in Figure 2.

The preparation of asphalt concrete specimens is done by compacting the HMA in molds. The compaction method and size of molds differ between the two design methods. Marshall mix design uses an impact compaction technique by freely dropping a hammer on the surface of a specimen molded in a “2 ½ inch x 4 inch” mold. Both faces of the specimen are compacted with 35-75 blows depending on the simulated level of traffic (low to heavy). Marshall compactor and molds used are shown in Figure 3.

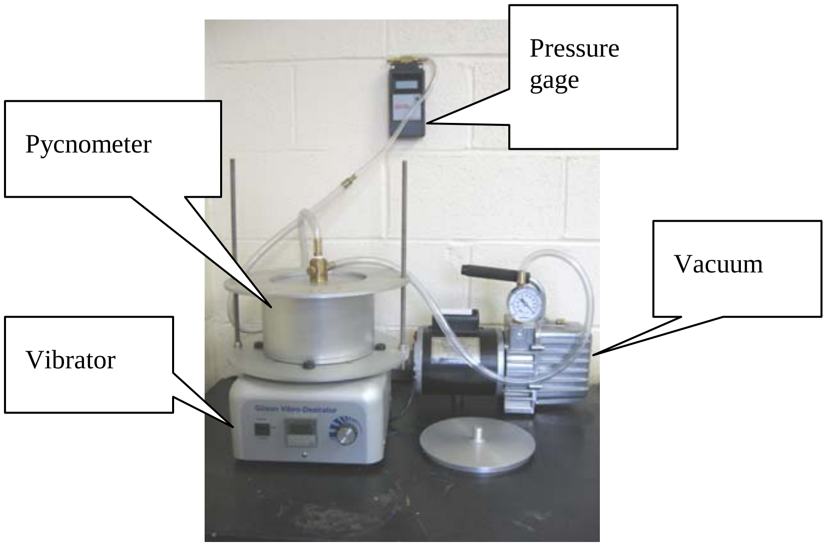


Figure 2 Assembly of equipment for the maximum specific gravity test

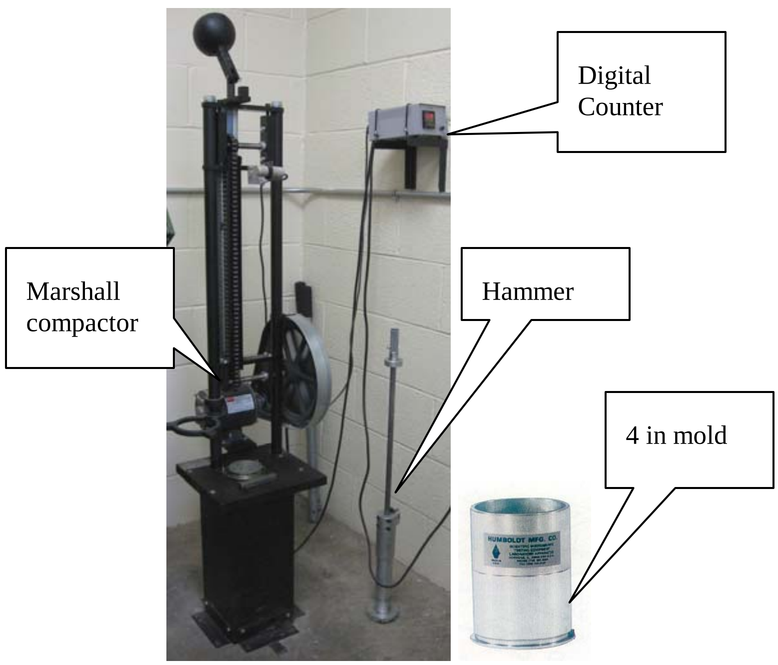


Figure 3 Marshall compactor and a 4 inch mold

The compaction method used in the Superpave procedure is accomplished using a different technique to better simulate the actual compaction effort achieved in the field. Superpave uses a gyratory compactor with a kneading action applying a contacting pressure of 600 KPa and an angle of gyration of 1.25°. The molds used in the Superpave are larger than the ones used in the Marshall mix design with dimensions of 150 mm (6 in) diameter and 250 mm in height. The number of gyrations applied to the specimen corresponds to the amount simulating the design traffic. An example of the Superpave gyratory compactor and its associated mold are shown in Figure 4.

Different than the Superpave design method, the Marshall method contains a destructive test for specimens to obtain data that is used to calculate the flow and stability of the designed mix. This process is completed using the

Stabilometer testing equipment shown in Figure 5. The stabilometer is used to measure the maximum load that a specimen can carry before failure, and the corresponding deflection at that instant.

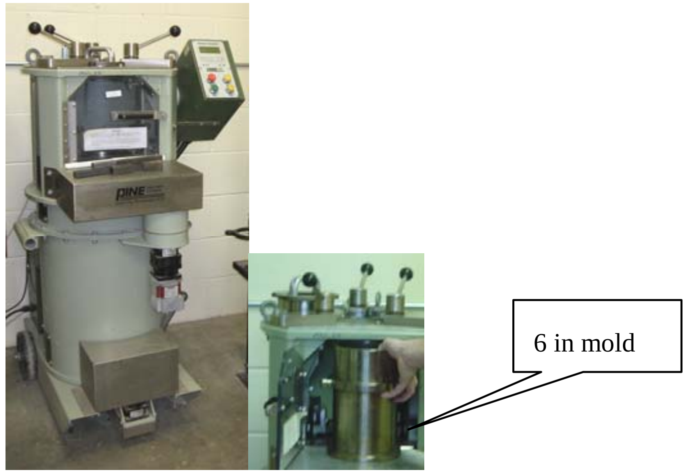


Figure 4 Superpave gyratory compactor and a 6 in mold

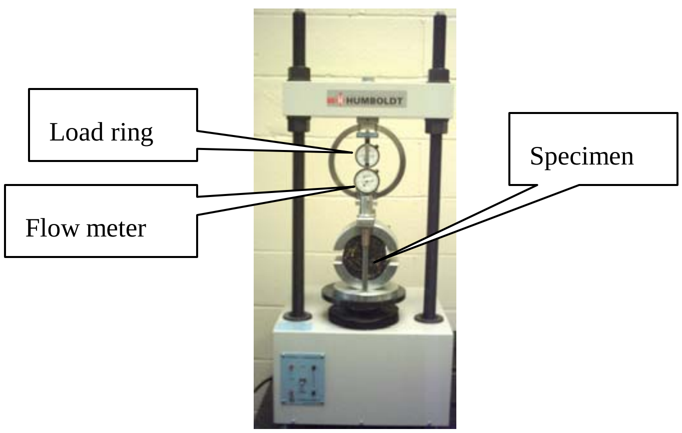


Figure 5 Marshall stabilometer

The above described pieces of equipment are mainly used in the process of mixing, compacting and testing the strength of the designed mix. A main test used to determine the mixing and compaction temperature is the viscosity test of the asphalt (binder). The Brookfield viscometer shown in Figure 6 is useful for this purpose.

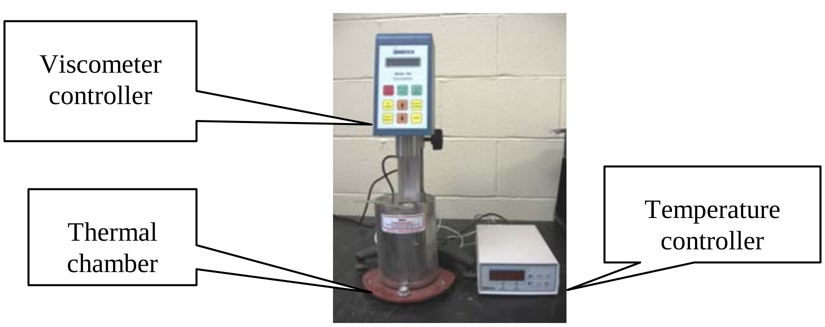


Figure 6 Brookfield viscometer

LABORATORY PROCEDURE, FIELD ACTIVITIES AND STUDENTS REPORTS

Students are divided into groups of three or four. Because the number of pieces of equipment are limited, only one group can utilize the laboratory at any given time. Each member in a group is required to submit a comprehensive report for the Superpave mix design and a similar report for the Marshall mix design. The formatting of the report is discussed in a later section. All of the laboratory procedures follow both the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM). The following subsections summarize the viscosity test, the Superpave mix design procedure, and the Marshall mix design procedure with samples of the students work when applicable.

Viscosity of the asphalt

Asphalt cement can be graded using a special designation which starts with the letters "PG", that stands for Performance Graded and is followed by two numerical values which represent temperatures for the high and low temperature grade, such as PG 64-22. For this binder, "64" is the high temperature grade and is the 7-day maximum pavement design temperature in degrees centigrade for the pavement temperature. The low temperature grade, "-22," is the minimum pavement design temperature in degrees centigrade considered for the design. PG 64-22 is the asphalt cement used in this laboratory. The first test conducted in the laboratory is the measurement of the viscosity of the asphalt that will be used in preparing the HMA specimen so that temperature ranges of mixing and compaction of the HMA can be determined. The procedure is given to the students as a summary of the detailed procedure stated in "ASTM D4402 – Viscosity Determinations of Unfilled Asphalt Using the Brookfield Thermosel Apparatus". Students are required to report the results of their viscosity measurments at 135° C and 165° C respectively and plot the viscosity vs temperature on a semilog scale. The desired viscosity range for mixing is between 0.15 and 0.19 Pa-s and 0.25 and 0.31 Pa-s for compaction. Figure 7 shows an example of the students' results for viscosity test. For the chart shown, mixing temperature range is found to be (146-151) ° C and compaction temperature is found as (158-163) ° C.

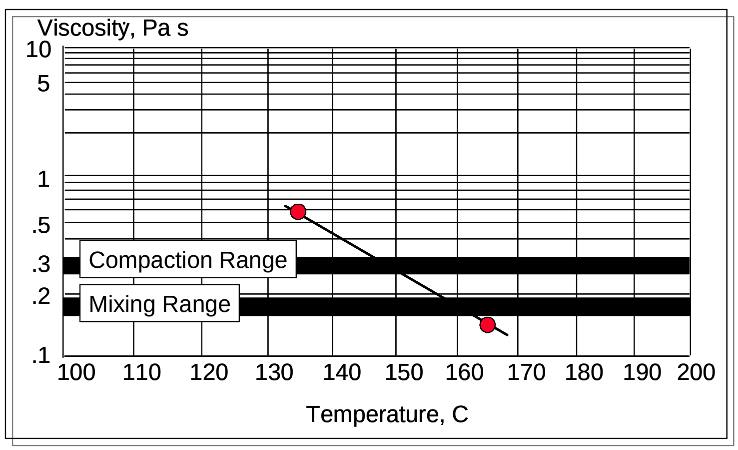
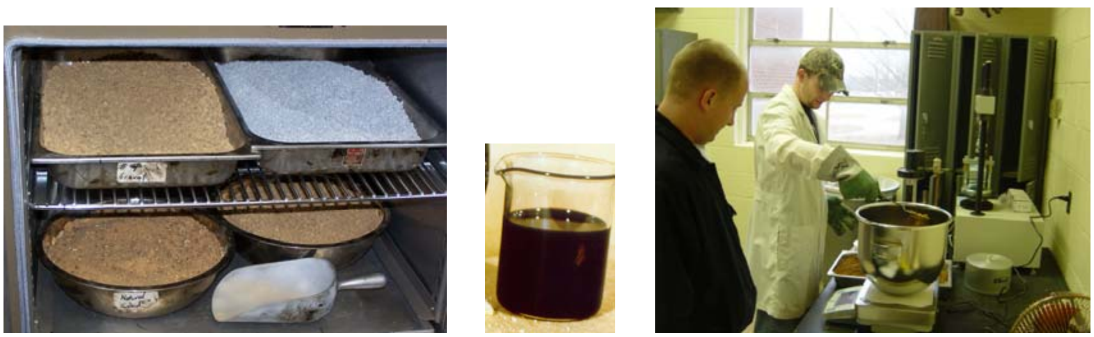


Figure 7 Results of a viscosity test to determine the mixing and compaction temperature

Marshall mix design

Marshall mix design is one of the oldest design methods used. Developed by Bruce Marshall for the Mississippi Highway Department in the late 30's, this method is still widely used by most states. The Marshall method criteria allows the engineer to choose an optimum asphalt content to be added to specific aggregate blend to a mix where the desired properties of density, stability and flow are met. The Marshall method uses standard HMA samples that are 4 inches in diameter and 2 1/2 inches high. The preparation procedure is carefully specified, and involves heating, mixing, and compacting asphalt/aggregate mixtures. Once prepared, the samples are subjected to a density-voids analysis and to a stability-flow test. The procedure is given to the students as a summary of the detailed procedure stated in: "ASTM D1559-Resistance to Plastic Flow of Bituminous mixtures using Marshall Apparatus", "ASTM D2726 Bulk Specific Gravity of Compacted Bituminous Mixtures", and " ASTM D 1559 Marshall stability and flow of asphalt concrete". All materials for the asphalt laboratory are donated by local companies and vendors. Four different types of aggregates are used for the trial blend: #7 Gravel (58%), Manufactured Sand (7%), #10 soft volcanic materials (25%), and Natural sand (10%). They are placed in the oven to dry to a constant temperature at 165° C. Figure 8-a shows the aggregates used in the laboratory. Due to a tight laboratory schedule, aggregate proportions, specific gravities, grain size distribution, and other aggregate properties are obtained from the aggregate provider. Students are already familiar-from previous courses- with the basic tests that determine aggregate properties. The asphalt binder used is a PG 64-22 and shown in Figure 8-b. Three specimens are prepared at each of the four percentages of the asphalt at 4.5%, 5.0%, 5.5%, and 6.0% (Percentage of weight of the total mixture). The heated aggregates and the asphalt cement are mixed thoroughly in the mixer as seen in Figure 8-c. Each mix is prepared to weigh 2200 grams for each specimen. A portion of the loose mix (1000 g) is used to establish the maximum specific gravity (G_{mm}) test (Rice test) and the rest of the loose mix are poured in the 4 in mold. The G_{mm} test is conducted following the AASHTO T 209-94 "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures" and using the Rice test apparatus shown in Figure 2. The HMA in the mold is compacted using the Marshall compactor described previously. Both faces of the specimen are compacted with 75 blows to simulate a heavy traffic greater than 1 million Equivalent Single Axle Load (ESAL). Samples are extruded from molds and left to cool down before starting the bulk specific gravity (G_{mb}) test: ASTM D2726 Bulk Specific Gravity of Compacted Bituminous Mixtures. The stability and flow tests are run using the semi-circular test head in conjunction with the Marshall testing machine shown in Figure 5 above. The stability of the sample is determined at the peak load crushing the sample in the loading head in Newtons. The flow is also measured as the highest deflection at the peak load in increments of 0.01 in.



(a) (b) (c)

Figure 8: (a) 4 types of aggregate (b) Asphalt binder PG 64-22 and (c) weighing material in mixing bowl

G_{mm} and G_{mb} densities are then used to calculate the volumetric parameters of the HMA. Measured void expressions are usually: Air voids (Va), sometimes called voids in the total mix (VTM), Voids in the mineral aggregate (VMA), and Voids filled with asphalt (VFA). Equations 1, 2, and 3 show how to calculate the volumetric parameters Where, P_b is the percentage of binder content used and G_{sb} is the bulk specific gravity for the blended aggregate.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100 \ldots \text{equation (1)}$$

$$VMA = \left(1 - \frac{G_{mb}(1 - P_b)}{G_{sb}}\right) \times 100 \ldots \text{equation (2)}$$

$$VFA = \frac{VMA - V_a}{VMA} \ldots \text{equation (3)}$$

The optimum asphalt binder content is finally selected based on the combined results of Marshall Stability and flow, density analysis and void analysis. Plots of asphalt binder content versus measured values of air voids, unit weight, flow, Marshall stability, %VFA, and %VMA are generated. Best fit of the plotted points generally have the trends shown in Figure 9. Optimum asphalt content is selected corresponding to air voids of 4%. The values of the other properties at this percentage of asphalt binder are determined and compared to specifications. Example of specifications used is shown in Table1.

To complete the Marshall Mix design, students are required to write a detailed report using the results of the work done with a discussion of the results and conclusions drawn. Students are also required to complete standard forms for the measurements and calculations obtained through the design process.

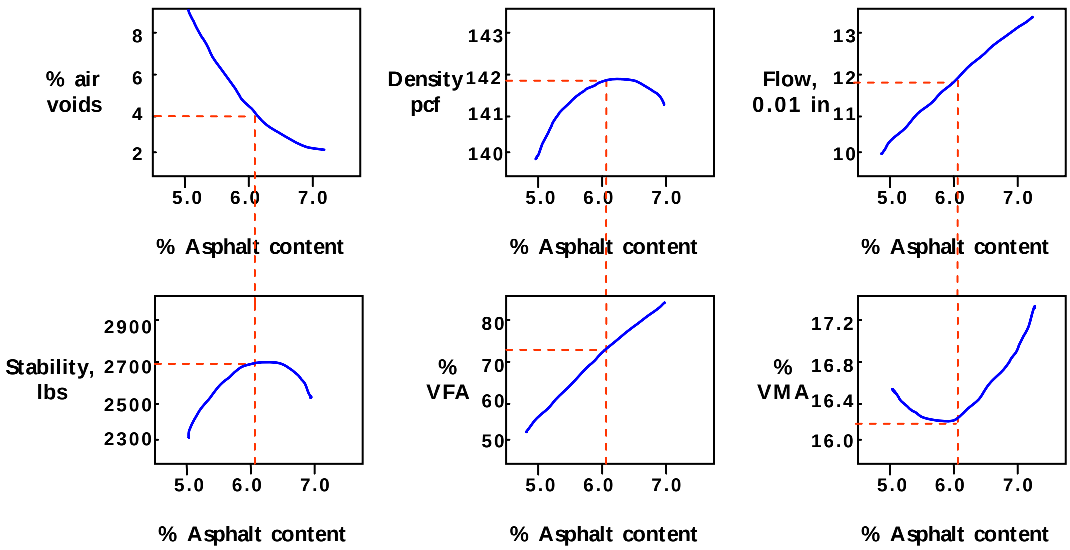


Figure 9 Asphalt binder % vs measured values

Table 1 Typical Marshall Design Criteria [AI, 2]

Mix Criteria	Light Traffic ($<10^4$ ESALs)		Medium Traffic ($10^4 - 10^6$ ESALs)		Heavy Traffic ($>10^6$ ESALs)	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction (number of blows on each end of the sample)	35		50		75	
Stability	2224 N (500 lbs.)		3336 N (750 lbs.)		6672 N (1500 lbs.)	
Flow (0.25 mm (0.01 in))	8	20	8	18	8	16
Percent Air Voids	3	5	3	5	3	5

Superpave mix design

Superpave stands for Superior Performing Asphalt Pavements. Superpave was initially developed by the Strategic Highway Research Program (SHRP) (1987-1993) [SHRP, 4] and it continues to improve. Some of the goals of this method are to improve previous HMA design methods. The goals are: (1) better incorporation of traffic and climatic conditions, (2) better asphalt binder and aggregate evaluation and selection and (3) better volumetric approaches to mix design. Differences between the Superpave and the Marshall mix design methods are mainly in the selection procedure of the materials, the compaction method, specimen dimensions, void analysis approach and specifications.

The students are required to determine whether the initial asphalt cement meets SHRP LEVEL-I volumetric mix design criteria or not. The initial asphalt content of PG 64-22 should be varied from 4.5 % to 6.0 % with 0.5% increments for the used aggregate blend with 1/2 inch nominal maximum sieve size. The same four different types of aggregates used in the Marshall method are also used in the Superpave method. A design traffic level used is a low volume at 0.5 million (ESAL) and an average design high temperature of 38 degree C. Two specimens are prepared and used for testing at each asphalt content. Heating and mixing the HMA are done in a similar fashion to the

Marshall procedure. The HMA in the Superpave mold is compacted using the Superpave gyratory compactor shown in Figure 4 above and the machine is pre-set to 117 gyrations. The preparation of the specimen follows "AASHTO TP 4-93 Preparing and Determining the Density of Hot Mix Asphalt Specimens by Means of the SHRP Gyratory Compactor" The number of gyrations corresponds to the specified level of traffic. The G_{mm} is also determined following "AASHTO T 209-94 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures". G_{mb} is calculated through "AASHTO T 166-93 Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens". As an output of the gyration process, the height of specimen corresponding to the gyration number is obtained. Since the specimen mass and crossection are constant through compaction, the density is continually calculated based on height. A Table of densification data and densification curves for the selected aggregates at different asphalt contents are obtained. An example of the densification curves is shown in Figure 10. Figure 10 shows the relationship between the number of gyrations and the % G_{mm}.

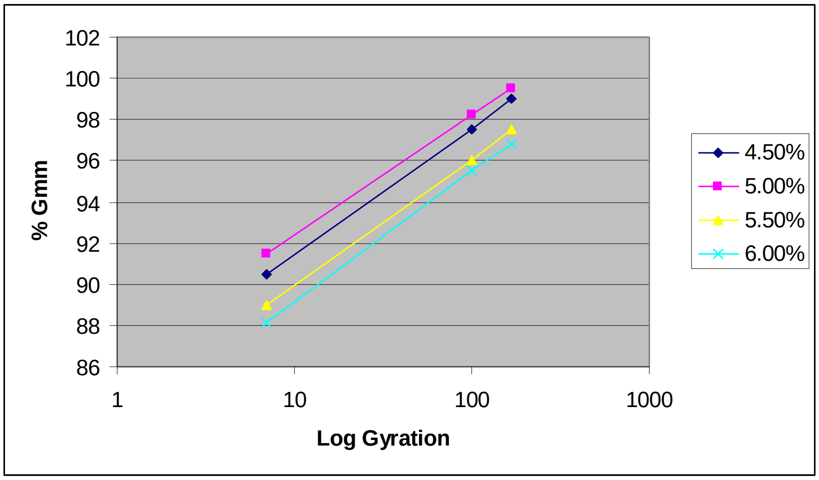


Figure 10 Densification curves at different asphalt contents

There are three points of interest on the densification curve – $N_{initial}$ which is a measure of mixture compatibility. N_{design} is the number of gyrations required to produce a density in the mix that is equivalent to the expected density in the field after the indicated amount of traffic. In the mix design process, as asphalt binder content is selected that will provide four (4) percent air voids when the mix is compacted to N_{design} gyrations. $N_{maximum}$ is the number of gyrations required to alert for rutting possibilities. The air voids at $N_{maximum}$ are required to be a least two percent. The three points mentioned are selected based on design traffic level and air temperature. Plots of asphalt binder content versus measured values of air voids, %VFA, and %VMA are generated. The values of calculated properties at 4 % air voids are compared to specifications. Students are required to write a detailed comprehensive report for the work done to complete the Superpave Mix design with discussion of results and conclusions drawn. Students are also required to complete standard forms for the readings and calculations obtained through the design process similar to the Marshall mix design report.

Field activities in this class involved a visit to the asphalt laboratory at Jackson TDOT and asphalt laboratory and site construction for Ford construction company in Union City. A visit to the asphalt plant for Ford construction at Troy, TN was a great experience for students to see job mixes in bulk quantities. Speakers from asphalt companies were invited to represent the industry of asphalt as well.

SURVEY AND ASSEMENT

Each student was asked to complete an exit survey at the end of the semester to get feedback about the asphalt laboratory equipment usage, laboratory procedure clarity, mix design procedure clarity, and laboratory reporting. The survey was in the form of a questionnaire of 17 questions as follows:

1. What was your first impression when you spotted the lab equipment for the first time, worried? Interested?

2. What is your impression when you see the lab equipment now?
3. Did you find the equipment in the asphalt lab overall easy to use? (1. Easy……5. Difficult)
4. Which equipment was hardest to use?
5. Did you fully understand the Superpave mix design procedure? (1. Fully……5. Did not understand)
6. At work, How soon can you apply the Superpave mix design procedure, if you had to?
   1. Tomorrow 2. After one week review 3.Can not
7. Did you fully understand the Marshall mix design procedure? (1. Fully……5. Did not understand)
8. At work, How soon can you apply the Marshall mix design procedure, if you had to?
   1. Tomorrow 2. After one week review 3.Can not
9. Which mix design method would you choose if you are the responsible engineer? Why?
10. Would you recommend TDOT to adopt Superpave mix design? (Yes, No)
11. Do you think the laboratory reports are better written at the end of mix design or on a weekly- based?
12. Do you think that the lab handouts instructions are easy to follow?
13. Did you like the team work or you prefer to work alone?
14. Are there any topics you are having difficulty understanding? Specify
15. What can I do to help you understand the topics that are giving you trouble?
16. Is there anything that has been particularly good or bad about this laboratory you would like to tell me?
17. The information learned for time spent compared to other CE labs? More, Just Right, Less

Summary of questionnaire

Questionnaire results were helpful in the assessment of the newly developed laboratory in many means. Although the number of students filling the survey did not exceed ten students, they gave some general feed back that was useful. The students' first impression when seeing the equipment was answered unanimously as "interested" where as the students' impression at the end of semester elucidated in the comments as: "I know how to use it", "Good to operate" and "I love it", scoring an average of 2 (Easy=1, Difficult=5). The equipment "hardest to use" varied amongst the students with no agreement on one particular piece being identified. Sixty percent answered as fully understood both the Superpave and the Marshall mix design procedure and 40% had it as level number 2 out of five levels. 60% answered that they can apply the two methods after one week of review where as 40 % answered as are ready to implement both methods "Tomorrow". One hundred percent of the students settled on the Superpave method as the one to choose if it were their responsibilty. Comments on the preference of the Superpave over the Marshall were: "More comforTable using it", "Less room for error!", "More realistic", and "more reliable and more consistent" and obviously, all recommend TDOT to start adopting Superpave mix design. Laboratory procedure handouts were viewed as easy to follow for most experiments. There were some requests from students to increase the number of lectures (in class) on the explanations of the two design methods. Team work was approved by all students and agreed that the work would not have been done without everybody's effort. No negative comments were offered as students agreed that it was an exciting experience and some declared that because of this exposure to asphalt laboratory they are considering pavement design as a career.

CONCLUSIONS AND FUTURE WORK

The preparation and development of a new asphalt laboratory course is quite an experience. Locating a space, allocating funds, purchasing equipment, optimizing mix design procedure to accommodate equipment, and teaching the laboratory are part of this experience and are the main topics presented in this paper. Exposing the undergraduate student in the civil engineering concentration to the hands-on pavement design experience is of great importance. The development of the asphalt laboratory is successful, and it exposes the students to hands-on experience on different flexible pavement design methods. Students learned in this course how to follow standard procedure of tests and specifications requirements by AASHTO, present hand-written technical information in a clear and orderly manner, interpret results and make decisions necessary to improve design, and work in a team environment. The adaptation of the Marshall and Superpave mix design methods vary from state to state; therefore, the exposure to different design methods will prepare students more for their professional career. The questionnaire results and feedback show that students, many of which started internships in such related topics, found the laboratory very useful and constructive. Future improvement to this class include adding more tests such as the Dynamic Shear Rehometer (DSR) for testing binder "rheological" properties and the dynamic complex modulus. If budget is big enough, additional sets of equipment will be purchased to allow more students to work at the same time.

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