Asphalt mix design Using Matlab Computer Program

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Abstract. An accurate asphalt mix design is a big issue to produce high quality pavement layer. Introduce a computer program that can be used to design different types of asphalt concrete layers i.e. base, binder and surface course will be very helpful. Therefore, the authors are introducing Asphalt Mix Design by MATLAB Program (AMDMAP) software to be used as a replacement to the manual calculations. The input data such as the characteristics of the used materials and lab work results must be available to run this program. The main output will be indicating the optimum asphalt content. Also, the relationships between Marshall Stability, Marshall flow, mixture density, Air Voids, Voids in Mineral Aggregate and Voids Filled with Asphalt vs different contents of asphalt will be produced. Mixture properties at optimum asphalt content will be indicated. Furthermore, the results will be compared with the standard specification of roads in Iraq.

1. Introduction
Hot asphalt mix design for road construction is a delicate procedure that controls the final product quality and long term performance. A good, optimal and suitable proportioning of constituents based on specific criteria are fundamentals to the construction materials production that enable pavement structure to withstand due to the growing of road traffic. Belgian Road Research Centre (BRRC) Recommendations for asphalt mix design have been introduced in according to the method of a code of good practice [1]. Hot mix asphalt design process involves four complementary phases [2]:
I. Materials: select, characterization and compared with the specifications.
II. Asphalt mix design: analytical study to identify the fundamental ingredients.
III. Indicate voids in mineral aggregate (VMA) and air voids.
IV. Experimental verification: Testing the mechanical properties of the designed mix.

Another analytical mix design procedure has been established by the Belgian Road Research Centre which was based on a volumetric approach [3]. This procedure was altered under the form of a software program which is presently used in practice in Belgium which is called PRogram for Asphalt mix Design and Optimisation (PRADO). Firstly continuously graded mixes was used in this procedure then generalized and validated for a wide variety of mix types.

Hot asphalt mix design is one of the main concerns that is affected the performance of the road pavement layers in the field. So, it has to be optimal and precise. In Iraq such as many other countries around the world there is no computer software that is adopted by the government or the organization that is responsible for asphalt mix design approval for roads and airports. In this research, a team work from
university of Kufa introduced a computer program which can be used to design different types of asphalt concrete layers i.e. base, binder and surface course. The input data such as the characteristics of the used materials and lab work results must be available to run this program. The main output will be indicating the optimum asphalt content.

2. Standard Marshall Mix design
Based to the State Commission of Roads and Bridges in Iraq [4], finding the optimum asphalt content for any asphalt mix requires several laboratory works and hand calculations to achieve the desired properties.

So developing a computer program that can go through the calculation process which it contains curve fitting, finding maximum value of fitted curve, substituting into multiple equations. All these steps would be a bit challenging to get accurate results. Since asphalt content is the most expansive ingredient in the asphalt mix the designer should be more conservative for its value.

The following steps must be covered to indicate the optimum asphalt content for base, binder or surface course hot asphalt mixture [4]:

2.1 Materials
Fine aggregate, coarse aggregate, mineral filler, asphalt cement and any other additives must tested and compared with the required specifications.

2.2 Composition of Mixtures
The asphalt concrete mixtures for base course (type I), binder course (type II) and surface course (type IIIA or type IIIB) shall be basically composed of coarse aggregate, fine aggregate, mineral filler, and asphalt cement. The mineral ingredients will be sized, uniformly graded and blended to meet the grading requirements for the particular type under contract. To such compound blended aggregate (considered as 100% by mass), asphalt cement shall be added within the percentage limits specified for the particular type in the specifications [4].

The requirements for the hot asphalt mix shall conform to grading shown in Table 1.

| Sieve size, mm | Type I Base course | Type I Binder course | Type II | Type IIIA Surface course | Type IIIB |
|---------------|-------------------|---------------------|--------|------------------------|---------|
| 37.5          | 100               |                     |        |                        |         |
| 25            | 90-100            |                     | 100    |                        |         |
| 19            | 76-90             | 90-100              | 100    |                        |         |
| 12.5          | 56-80             | 76-90               | 90-100 | 100                    |         |
| 9.5           | 48-74             | 56-80               | 76-90  | 90-100                 |         |
| 4.75          | 29-59             | 35-65               | 44-74  | 55-85                  |         |
| 2.36          | 19-45             | 23-49               | 28-58  | 32-67                  |         |
| 300m          | 5-17              | 5-19                | 5-21   | 7-23                   |         |
| 75m           | 2-8               | 3-9                 | 4-10   | 4-10                   |         |

Asphalt cement content (% weight of total mix)

Table 1. Asphalt Mixture Grading [4].

Finally, the aggregate shall be uniformly graded and within the range between the low and high limit on each adjacent sieves.

2.3 Hot Asphalt Mixtures requirements
Asphalt concrete mixtures shall have the properties shown in Table 2 when compacted by 75 blows on each face with a standard Marshall hammer [4].
Table 2. Asphalt mix properties requirements [4].

| Property                                      | Base course | Binder course | Surface course |
|-----------------------------------------------|-------------|---------------|----------------|
| Resistance to plastic flow (ASTM D1559) 75 blows/face |             |               |                |
| Marshall Stability (min.), KN                 | 5           | 7             | 8              |
| Marshall flow, mm                             | 2-4         | 2-4           | 2-4            |
| Air voids in Marshall specimen, %             | 3-6         | 3-5           | 3-5            |
| Voids in mineral aggregate (min.), %          | 12          | 13            | 14             |

ASTM D6927 and asphalt institute procedures, Marshall Mix design method is used to determine optimum asphalt cement content [5,6]. Several specimens are prepared with i.e. 4, 4.5, 5, 5.5 and 6% by mass of aggregate asphalt cement contents. Firstly, bulk and theoretical specific gravity of asphalt mixtures are indicated based on ASTM D2726 and ASTM D2041. While, ASTM D3203 has been followed to determine air voids. Then, Marshall stability and flow are implemented by Marshall testing machine for each specimen. Lastly, the optimum asphalt cement for asphalt mixture is determined. Indicating the optimum asphalt content needs many calculations to determine mixture dry density, Air Voids (AV), Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA) that are determined from eqs. (1–4), respectively.

\[
dry\ \text{density} = \frac{\text{weight in air}}{\text{SSD weight} - \text{weight in water}}
\]

where SSD is the mass of the saturated-surface dry specimens, gm.

\[
Air\ \text{voids, \%} = \left(1 - \frac{\text{dry\ \text{density}}}{SG_{\text{max}}}\right) \times 100 \%
\]

where SGmax is theoretical specific gravity of the mixture which is determined according to ASTM D2041 or by using eq. 5.

\[
VMA = 100\% - \frac{G_{mb} \times p_s}{G_{sb}}
\]

where \( p_s \) is percentage of aggregate in the total mix and \( G_{sb} \) is bulk specific gravity of aggregate (eq. 6).

\[
VFA = \frac{(VMA - AV)}{VMA} \times 100
\]

\[
G_{mm} = \frac{100}{\frac{CA}{SG_{CA}} + \frac{FA}{SG_{FA}} + \frac{F}{SG_{F}} + \frac{A}{SG_{A}}}
\]

Where: CA, FA, F and A are coarse aggregate, fine aggregate, filler and asphalt percentages by mass of total mix, respectively.

SGCA, SGFA, SGF and SGA are coarse aggregate, fine aggregate, filler and asphalt specific gravity, respectively.

\[
G_{sb} = \frac{p_1 + p_2 + \cdots + p_n}{G_{s1} + G_{s2} + \cdots + G_{sn}}
\]

Where \( p_1; p_2; p_n \) are percentages of individual aggregate type by total mass of aggregate and \( G_{s1}; G_{s2}; G_{sn} \) are bulk specific gravities of individual aggregate type.

Then optimum asphalt cement content (OAC) can be obtained from eq. 7.

\[
OAC = \frac{1}{3} \left[ AC_{\text{max.stability}} + AC_{\text{max.density}} + AC_{\text{mid range of air viods}} \right]
\]
\[ G_{se} = \frac{100 - \rho_b}{\frac{100}{G_{mm}} + \rho_b} \]

Where: \( G_b \) = Specific gravity of asphalt  
\( G_{se} \) = Effective specific gravity of aggregate

3. Program for Asphalt mix Design

In this section, an overview on the proposed computer program, by using MATLAB software, which can be used to design different types of asphalt concrete layers i.e. base, binder and surface course is presented. The input data such as the characteristics of the used materials and lab work results must be available to run this program. The main output will be indicating the optimum asphalt content. Also, different relationships between different asphalt content and MS, MF, asphalt mix density, AV, VMA and VFA are drawn and compared with the Iraqi specifications.

3.1 MATLAB programming

MATLAB is a high performance programming platform mainly designed for engineers and scientist and it excels in viewing and analyzing data. Using MATLAB we can perform many tasks such as algorithms development, data analysis and easily create models and applications. The uncountable built in functions in MATLAB enable users to explore several ways to quickly reach the desired solutions. MATLAB version R2014a has been used in programming AMDMAP [7].

3.2 Asphalt Mix Design by MATLAB Program (AMDMAP) software

The Asphalt Mix Design by MATLAB Program AMDMAP software package can be used as an analytical mix design tool developed by the authors of this paper to indicate the optimum asphalt content. This is the first version of the program operates on a WindowsTM platform. A graphical user interface (GUI) has been created to enable users to input the data and get the results without the need for any prior knowledge about MATLAB as shown in Figure 1. Each mix design study in AMDMAP consists of 5 steps and depends on the materials characterization and the laboratory results of five asphalt cement contents i.e. 4, 4.5, 5, 5.5 and 6%:

1. Indicate asphalt mix type: Input the asphalt mix type that is corresponding to surface, binder or base course;
2. Marshall Stability and flow: input Marshall stability and flow results for each individual asphalt cement content i.e. 4, 4.5, 5, 5.5 and 6% by total mass of aggregate.
3. Characterization of all the different aggregate fractions and asphalt cement. For each aggregate component the specific gravity and content (% passing by total weight of aggregate), are required. Furthermore the specific gravity of asphalt cement is required;
4. Theoretical (maximum) specific gravity: the magnitude of the theoretical specific gravity (G_{mm}) can be indicated by conducting ASTM2041 or applying eq. 5. Its worthy to state that effective specific gravity of aggregate (G_{se}) is obtained from eq. 8.
5. Optimum asphalt content determination: using the input information on the aggregate components and asphalt properties, optimum asphalt content can be determined by running AMDMAP software. Also, different aggregate component will be indicated by percentage of the total weight of the mix.
6. Mixture properties: the volumetric properties i.e. AV, VMA and VFA and the mechanical properties i.e. MS and flow at the optimum asphalt content will be reported by AMDMAP software. Finally, the relationship between different asphalt content and mix density, MS, MF, AV, VMA and VFA will be drawn and the optimum asphalt content will nominated and compared with the specification in accordance to State Commission of Roads and Bridges [4].
4. Case study

Aggregate components and properties available for hot asphalt mix design for a surface course layer are: bulk specific gravity for coarse aggregate (aggregate 1) = 2.630, bulk specific gravity for fine aggregate (aggregate 2) = 2.675, bulk specific gravity for mineral filler (aggregate 3) = 3.14. Coarse aggregate, fine aggregate and filler (by total mass of aggregate) are = 40%, 53% and 7%, respectively. The specific gravity of asphalt cement= 1.03 % and the maximum specific gravity of mixture Gmm = 2.425 at asphalt content = 5 %.

Different type testing have been conducted with different asphalt cement content i.e. 4, 4.5, 5, 5.5 and 6% and the results are shown in Table 3.
### Table 3. Asphalt mixtures properties with different asphalt content.

| % Asphalt content | Marshall stability (kN) | Marshall flow (mm) | Weight in air, gm | Weight in water, gm | Saturated-surface dry weight, gm |
|-------------------|-------------------------|--------------------|-------------------|---------------------|-------------------------------|
| 4                 | 8.7                     | 2.3                | 1191              | 675                 | 1201                          |
| 4.5               | 9.3                     | 2.5                | 1194              | 687                 | 1206                          |
| 5                 | 10.2                    | 3.0                | 1200              | 690                 | 1207                          |
| 5.5               | 10.0                    | 3.4                | 1203              | 696                 | 1208                          |
| 6                 | 9.8                     | 3.6                | 1207              | 696                 | 1210                          |

The first step to indicate the optimum asphalt content and compare the results with the adopted specification by using AMDMAP software is input the required information as shown in Figure 2.

![Geographical user interface with the case study input data.](image-url)
The second step is press Run then save to pdf to produce the results and output data. Figure 3 shows the input data while the output data is shown in Figure 4 and Figure 5. Furthermore, a detailed report will be saved as pdf file which is shown in Appendix 1.

Chapter 1. Experiment Input Data

Table 1.1. Marshall Stability and Flow

| Course Type | Marshall stability | Marshall flow |
|-------------|-------------------|---------------|
| 4%          | 8                 | 2.3000        |
| 4.5%        | 9                 | 2.5000        |
| 5%          | 10.5000           | 3             |
| 5.5%        | 10                | 3.4000        |
| 6%          | 9                 | 3.6000        |

Table 1.2. Details of Aggregates

| Percentage passing by total weight of aggregates | Specific Gravity |
|-------------------------------------------------|------------------|
| 1                                               | 49               | 2.63            |
| 2                                               | 53               | 2.675           |
| 3                                               | 7                | 3.14            |

Table 1.3. Maximum bulk specific gravity

| Weight in Air | Weight in Water | SSD  |
|---------------|-----------------|------|
| 1191          | 675             | 1201 |
| 1194          | 687             | 1206 |
| 1200          | 690             | 1207 |
| 1203          | 696             | 1208 |
| 1207          | 696             | 1210 |

Figure 3. Input data of the case study as shown in the pdf file of the report.
Chapter 2. Experiment Output Data

Table 2.1. Results in Percentage

| Type of Aggregate   | Content in % |
|---------------------|--------------|
| Asphalt             | % 5.40       |
| 1                   | % 37.84      |
| 2                   | % 50.14      |
| 3                   | % 6.62       |

| Percentage %        |
|---------------------|
| Air void at Optimum asphalt content | % 3.47 |
| VMA at Optimum asphalt content    | % 17.51 |
| VFA at Optimum asphalt content    | % 80.07 |

Figure 4. Output data of the case study as shown in the pdf file of the report.

From Figure 3, it is clearly shown that the optimum asphalt content is 5.4% by total weight of mix while other compound percentages are 37.84, 50.14 and 6.62% for coarse aggregate (aggregate 1), fine aggregate (aggregate 2) and filler (aggregate 3). Also, the volumetric properties i.e. AV, VMA and VFA at optimum asphalt content were reported.

On the other hand, the relationships between different asphalt content and MS, MF, Density, AV, VMA and VFA are presented in the report. On each figure the upper and lower limit of each property are
shown and the corresponding result for each one at optimum asphalt content is clearly presented. The results show that all asphalt mix properties at optimum asphalt content are within limitation and comply with the specification.

5. Conclusion
In Iraq such as several other countries around the world there is no computer software that is adopted by the government or the organization that is responsible for asphalt mix design approval for roads and airports.
Asphalt Mix Design by MAtlab Program (AMDMAP) software is introduced by authors to design different types of hot asphalt mixtures suitable for surface, binder or base course.
The input data comprise materials characterization, aggregate compounds and percentages, type of mix, volumetric and mechanical properties of individual mixtures i.e. for mixtures with 4, 4.5, 5, 5.5 and 6% asphalt cement.
While the main output will be the optimum asphalt content and the aggregate compounds percentages by weight of the total mix.
Furthermore, the relationships between MS, MF, mixture density, AV, VMA and VFA and different contents of asphalt is produced. Mixture properties at optimum asphalt content is indicated and compared with the standard specification for roads in Iraq.

6. References
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