HOTMIX!

HOT MIX ASPHALT DESIGN EXPERT SYSTEM

FINAL REPORT IR-90-02

September 1990

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A report to the Alabama Highway Research Center

Dr. Frazier Parker, Director

HOTMIX! - Hot Mix Asphalt Design Expert System

I. Introduction

HOTMIX! is a expert system computer program created to assist in the design of asphalt aggregate mixes. This program assists the hot mix asphalt design engineer in creating the design, making the laboratory mixture, and evaluating the results. The strength of the program is it's ability to provide specific advice on improving the mix to bring it into compliance.

HOTMIX! provides advice with two tools - hypertext and the inference engine. Hypertext allows the user obtain background information pertaining to certain "hot" words (text) or phrases on the screen. When the user places the cursor on a hypertext word (denoted by being highlighted on the screen), a pop-up window appears that gives more information on the word/phrase in question. Hypertext appears throughout HOTMIX!.

The inference engine is what makes HOTMIX! "smart". This part analyses the results of the laboratory mix design and tests, and reasons, after a fashion, reaching conclusions that tell the user if the mix is within the specifications. If it is out of specification, the engine triggers advice on how to bring it into compliance. The ability to only trigger the advice needed for the problems the mix at hand has makes this part of the program unique.

HOTMIX! expertise was generated from experts in industry, government and academe, listed in the Acknowledgments. Using these three different viewpoints removed the potential for bias from any one organization's purposes and experience. The functioning and purpose of the program was defined by these experts as the program was being developed - making it useful to the profession.

HOTMIX! was developed using 1st Class HT expert system development tool. HOTMIX! offers expert advice and background information on each step in the mix design process. HOTMIX! has the following features:

* An Aggregate Blending Program which allows blending and automatic plotting of several aggregate stock piles and mineral fillers into a blend that fits one of three FHWA specifications.

* A Marshall Mix lab data reduction program, including onscreen plotting.

* The Asphalt Institute Marshall Mix design procedure. HOTMIX! does this by examining the plotted data, retrieving the appropriate peak values and making the optimum asphalt content calculation.

Plots of flow, stability, voids in mineral aggregate (VMA), voids filled with asphalt (VFA), unit weight, and air voids (AV) versus the percent of asphalt cement contained in the mix are created by using the Marshall mix procedure and the Marshal mix design. The program uses four percent air voids to calculate the optimum asphalt cement content, stability, VMA, VFA, and flow.

The program uses these values to determine if a supported parameter is inadequate. The parameters that are supported are flow, stability and VMA. If a parameter falls outside the accepted values, the program gives advice to help solve the problem. The advice given was gathered from interviews with recognized experts in the field of asphalt design.

Specific instructions on running HOTMIX! are included in the companion user's manual.

II. Program Format

HOTMIX! is composed of the following sections:

Asphalt Preparation
Blend Preparation
Marshall Mix Procedure
Marshall Mix Design

The structure of each of these sections is discussed below.

A. Asphalt Preparation (Information Only)

This section contains general information about the asphalt cement needed to make the pills used in the Marshall Mix Procedure. It is included for the benefit of those new to the area of asphalt design. The purpose is to provide a basic understanding of the asphalt specification. The following information is included:

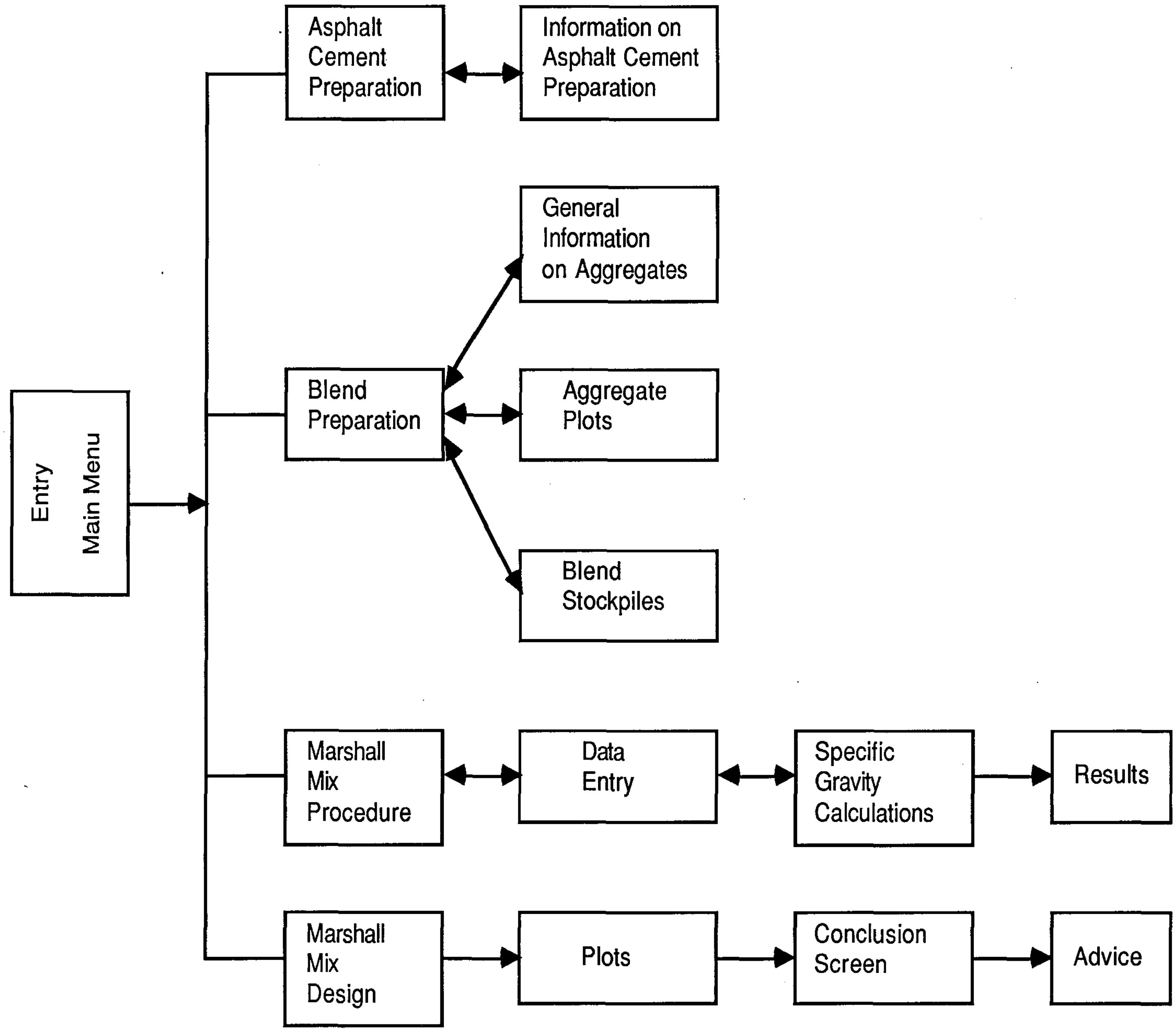
One gallon of asphalt cement is needed to make the asphalt concrete pills. Be sure a sufficient quantity is on hand to make all the pills from one batch of asphalt cement. Using different asphalt cements in the same batch may cause mixed results. Make sure the correct viscosity-graded asphalt cement is being used [AC-20 is typical].

The asphalt cement should come from the same supplier that the contractor is planning to use on the job. Slight differences in asphalt cement may cause differences between the lab mix and performance of the mat in the field. If the asphalt cement the contractor will use is not available, use an asphalt cement of the same grade.

There is much that is not yet understood about asphalt cement. Consequently, sometimes two asphalt cements that meet the ASTM specification will perform differently. Therefore, it is important to use the same asphalt cement in the lab as will be used in the field.

Penetration-graded asphalt cements are sometimes used. The specifications for these are given in ASTM D946. (Appendix A)

Viscosity-graded asphalt cements are also commonly used. Their specifications are given in ASTM D3381. (Appendix B)


Entry
Main Menu
Asphalt Cement Preparation
Information on Asphalt Cement Preparation
General Information on Aggregates
Blend Preparation
Aggregate Plots
Blend Stockpiles
Marshall Mix Procedure
Data Entry
Specific Gravity Calculations
Results
Marshall Mix Design
Plots
Conclusion Screen
Advice

B. Blend Preparation

This section contains general information on aggregates. This part of the program allows the user to blend stockpiles graphically or numerically on the screen. The user can enter up to five different aggregates, specifying the grain size distribution and texture (whether the aggregate is crushed or natural) of each aggregate. The grain size distribution is specified by passing a sample through a set of sieves and recording the percent of the sample that is retained on each sieve. The user then enters those percentages on an input screen. These gradations are then plotted onscreen, superimposed on the user-selected acceptable gradation range.

By choosing percentages of each aggregate gradation, the user is able to blend the aggregates together graphically. A composite gradation, consisting of the selected percentages of each aggregate, appears on the screen. The user can try different combinations of the gradation until the gradation curve falls within the specification range. While selecting these percentages, the user can, at any time, view the combined gradation plotted on any of three variations of the Fuller curve.

General Information on the Fuller Plot. The Fuller plot is another way to represent a gradation. It is the aggregate grading chart recommended by the Federal Highway Administration (FHWA). The chart, based on a scale raising sieve opening to the 0.45 power, is very convenient for determining the maximum density line and for adjusting aggregate gradings. Gradations which closely approach the straight maximum density line generally give low VMA values and are often shifted away from it to increase the VMA values.

At least three different methods are currently used to plot the maximum density line. One method obtains the maximum density line by drawing a straight line from the origin at the lower left of the chart to the maximum (top) particle size at the top of the chart. (Figure 1).

Another method obtains it by drawing a straight line from the origin to the nominal maximum particle size at the top. The nominal maximum particle size is defined as the largest sieve size listed in the applicable specification upon which any material is retained. (Figure 2).

Still another way to obtain it is to draw a straight line from the origin to the percentage point plotted for the largest sieve with material retained. (Figure 3).

When plotting the GSD on the Fuller plot, observe the following:

1. The GSD should not be coincident with the Fuller line - it will surely have too low a VMA percentage, but high density.
2. Moving the gradation away from the Fuller line increases the VMA and reduces the density.
3. The gradation should not cross the Fuller line. Doing so will usually lead to a mix that segregates.
4. If gradation is above curve, but close to it, reduce percentage of coarse material.

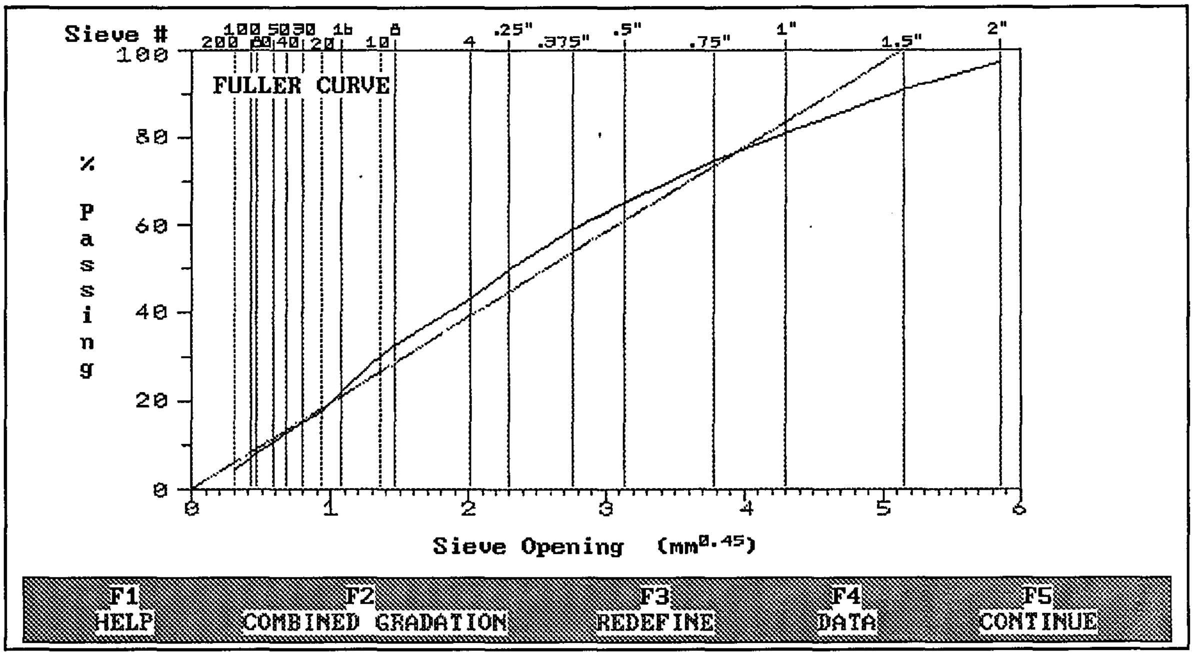


Figure 1: Fuller Plot A

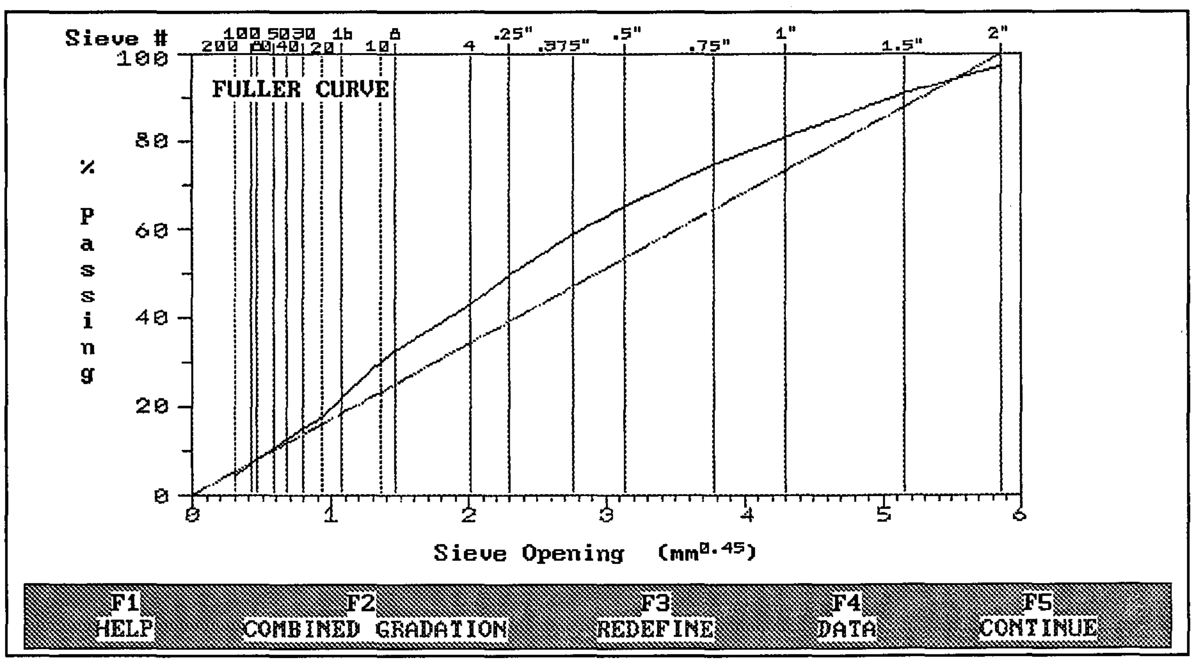


Figure 2: Fuller Plot B

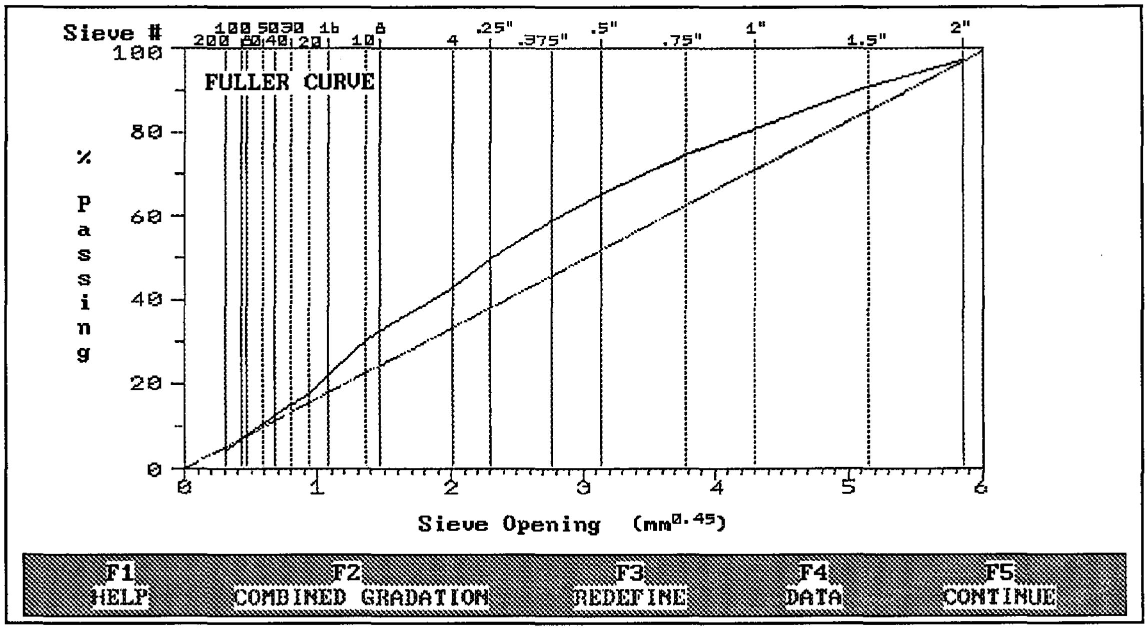


Figure 3: Fuller Plot C

5. Humps in the GSD should be avoided. A hump indicates that some of the particle sizes are missing. If this happens, you will get a dry, brittle mix.

Gradation ranges specified by the State of Alabama for low, medium, and high use roads are used. (State of Alabama Highway Department, 1985). The user selected blend is superimposed on the selected gradation range on screen to simplify blending.

Since HOTMIX! is a program to design asphalt aggregate mixes, general information on the nature and characteristics of aggregates is provided through hypertext. Hypertext includes information on aggregate categories: fine aggregate (usually taken as passing the #8 sieve), and coarse aggregate (larger than the #8 sieve). Aggregates can be either natural or crushed. Natural sands tend to be more rounded. This rounded characteristic is due to weathering. The advantage of natural aggregate is economics. The natural aggregates have little mechanical processing and are therefore available at a lower cost.

Crushed sands are created by crushing larger aggregates. They have a more angular shape. This increased roughness increases the coefficient of friction between particles in the aggregate. This leads to an increase in the strength of the mix, and also decreases the mix's ability to flush or bleed. All three of these characteristics are recognized as advantages. Crushed aggregates may be classified by their number of fractured faces (usually one or two).

The FHWA has recommended limits of the amount of natural sand that can be used in a mix, for higher volume roads. Mixes with too much natural sand tend to shove when compacted.

MINERAL FILLER. "Mineral filler" is any inorganic material that passes the no. 200 sieve. This material may be Portland cement, lime, baghouse fines, ground agricultural lime (if it does not contain particle sizes larger than no. 200), or material from wet washing aggregates (sump residue). Mineral filler should be entered as a separate stockpile. If ground agricultural lime has particle sizes larger than no. 200 sieve, the grain size distribution must be input, in order to blend it with the other stockpiles.

Gradation Ranges - low, medium, and high use roads. The State of Alabama specifies a range of gradations for each of three different levels of road use; low, medium, and high. The road classifications are based on how much traffic is anticipated for that road.

A) Low use road

The A gradation is usually used for base course of asphalt concrete. It is an open gradation with a 2.0 inch maximum aggregate size, used as the bottom asphalt concrete layer in the pavement structure. The gradation shown in the FHWA gradation taken from the "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects", FP-85, 1985.

B) Medium use road

The B gradation is usually used for binder course of asphalt concrete, placed between the base course (A) and the surface course (C). It is a fairly open gradation with a 1.5 inch maximum aggregate size. The gradation shown in the FHWA gradation taken from the "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects", FP-85, 1985.

C) High use road

The C gradation is usually used for surface course of asphalt concrete. It is a closed gradation with a 1.0 inch maximum aggregate size. This layer is used as the top asphalt concrete layer in the asphalt concrete pavement structure. The gradation shown in the FHWA gradation taken from the "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects", FP-85, (State of Alabama Highway Department, 1985).

C. Marshall Mix Procedure

The Marshall Mix Procedure section asks the user for information about the samples they are using. HOTMIX! uses this information to assist the user in making up the actual pills that are needed to run the stability, flow, unit weight, and Rice specific gravity tests. The following calculations are made:

The weight of aggregate needed from each stockpile to put in the mix to get the desired gradation.

The weight of aggregate needed from each sieve to put in the mix to get the desired gradation.

The information needed for these calculations is :

The total weight of the pill in air.

The asphalt percent based on the total weight.

This section also asks the user to give the asphalt percentage batch a name by which it can be referenced later. These names are used to distinguish between pills with the same asphalt cement percentage at a later point in HOTMIX!.

The theoretical maximum specific gravities and densities of asphalt paving mixtures are intrinsic properties that are determined by the type (natural or crushed) and gradation of the aggregate mixture. They are used to calculate values for percent air voids in compacted bituminous paving mixtures. They provide target values for the compaction of paving mixtures. They are essential when calculating the amount of bitumen absorbed by the internal porosity of the individual aggregate particles in a bituminous paving mixture.

The Rice method is used to calculate the theoretical maximum specific gravity and density of the mix (which includes the asphalt and the aggregate) by the ASTM D2041 (Appendix C). This program allows the user to select either the Rice Flask or Rice Bowl method to calculate the specific gravity of the mix.

The Rice method determines the specific gravity of the sample at 25°C. The Rice bowl method consists of:

1. Weigh the sample in air
2. Put the sample in the bowl
3. De-air the sample (place under vacuum)
4. Submerge the bowl with the sample in it
5. Weigh the submerged apparatus.
6. Calculate the theoretical maximum specific gravity by using equation 1.

$$G_s = A/(A-C) \qquad (1)$$

Where:

G_s - theoretical maximum specific gravity.

A - mass of the oven dry sample in air, g, and

C - mass of the water displaced by the sample at 25 °C (77 °F)

The Rice flask method consist of the following:

1. Weigh the empty flask,
2. Weigh the flask filled with water (calibration),
3. Empty flask,
4. Put mix in the flask, weigh it,
5. Fill the flask to the top with water, leave the mix in the flask, weigh it.
6. Calculate the theoretical maximum specific gravity using equation 2.

$$G_s = A/(A + D - E) \tag{2}$$

Where:

G_s - theoretical maximum specific gravity.

A - mass of the oven dry sample in air, g, and

D - mass of the container filled with water at 25 °C (77 °F)

E - mass of container filled with sample and water at 25 °C (ASTM, 1990)

After the specific gravity of the mix is calculated, the user is asked to enter the following:

Sample weight in air	W_{AIR}
Sample weight saturated surface dry (SSD)	W_{SSD}
Sample weight submerged	W_{SUB}
Flow	FLOW
Stability	STAB
Specific Gravity of the asphalt cement	G_{AC}
Sample diameter	SD
Total weight (lbs)	W_T
Total volume	V_T

Volume of the AC	V_{AC}
Weight of the aggregate	W_{AGG}
Volume of the aggregate	V_{AGG}
Specific gravity of the mix	G_{MIX}
Voids in mineral aggregate	VMA
Percent air voids	%AV
Unit Weight of pill	γ
Volume of voids	V_{void}
Voids filled with asphalt	VFA
Percent AC	%AC

HOTMIX! uses this information to perform the following calculations:

$$W_T = W_{AIR} / 453.6$$

$$V_T = (W_{SSD} - W_{SUB}) / 28317$$

$$V_{AC} = W_{AC} / (G_{AC} * 62.2)$$

$$W_{AGG} = W_T - W_{AC}$$

$$V_{AGG} = (W_{AC} + W_{AGG}) / (G_{MIX} * 62.2) - V_{AC}$$

$$VMA = ((V_T - V_{AGG}) / V_T) * 100$$

$$\%AV = ((V_T - V_{AGG} - V_{AC}) / V_T) * 100$$

$$\gamma = (W_T / V_T)$$

$$V_{void} = V_T - V_{AGG}$$

$$VFA = V_{AC} / V_{void} * 100$$

$$\%AC = W_{AC} * 100 / W_{AIR} * 453.6$$

After the calculations are completed a summary of this particular pill is given. The summary sheet contains the following information:

Alpha-numeric identifier:	
VMA:	____ %
VFA:	____ %
Volume of Voids:	____ ft^3
Percent Air Voids:	____ %

Pill:

Unit Weight:	____ lb/ft^3
Specific Gravity:	____
Diameter:	____ in

Weight: ____ lb
Volume: ____ ft^3
Asphalt Weight ____ lb
Asphalt Content ____ %

Asphalt Cement:
Specific Gravity: ____
Volume: ____ ft^3
Weight: ____ lb

Aggregate:
Specific Gravity: ____
SSD Specific Gravity: ____
Apparant Specific Gravity: ____
Absorption: ____ %
Volume: ____ ft^3
Weight: ____ lb
Stability: ____
Flow: ____ in/100

After examining the data the user is given the choice of

a) Continuing on to the Marshall Mix Design,

b) Entering another pill with the same percentage of asphalt cement,

or

c) Starting this section (Marshall Mix Procedure) again, but with a different percentage of asphalt cement.

D. Marshall Mix Design

The Marshall Mix Design section uses the information from the Marshall Mix Procedure to plot six key variables as a function of the percent of asphalt cement. The plots can be a useful tool in spotting inconsistency within the mix. The following six parameters are plotted versus the percentage of asphalt cement:

Stability
Air Voids
Voids Mineral Aggregate
Voids Filled with Asphalt
Flow
Unit Weight

The optimum asphalt cement is the numerical average of the peak values from the stability and unit weight plots along with the average of the limits for percent air voids. The Alabama Highway Department designs asphalt mixes based on four percent air voids. To accommodate this, the program calculates the optimum asphalt cement percentage by assuming four percent air voids. The results are summarized on the conclusion screen. A typical conclusion screen is shown below.

HOTMIX! has calculated these numbers.

The optimum AC is: ____ %

The stability is: ____ lbs.

The opt AV is: ____ %

The opt flow is: ____ in/100.

The opt VFA is: ____ %

The opt VMA is: _____ %

After all the calculations are completed, the program gives advice regarding how to alter stability, VMA, and flow that are too low or too high. Certain ranges, based on the expected amount of traffic, are used to determine if flow, stability, or VMA is high or low. HOTMIX! can be easily customized to use a different set of ranges. The ranges that are currently being used are given below in Table 1:

Table 1. Asphalt Parameter Values as a Function of Expected Traffic Levels

Traffic Level	Light		Medium		Heavy	
Boundary	Low	High	Low	High	Low	High
Parameter	500	None	750	None	1500	None
Stability	8	20	8	18	8	16
Flow	8	20	8	18	8	16
Air Voids	3	5	3	5	3	5

The advice that is given was obtained by interviewing several recognized experts in the field of asphalt pavement design.

The advice given by the program is presented below. It is broken down into suggestions and comments for each individual problem the program is designed to point out.

Problem	Comments/Suggestions
High Flow	COMMENTS:
	If the flow is high you will get a flexible mix.
	NEVER exceed maximum allowable flow. Use normal flow.
	SUGGESTIONS:
	TO DECREASE FLOW:
	Change the grade of AC.
	Use more gravel.
	Use a larger maximum particle size.
Low Flow	COMMENTS:
	If the flow is low you will get a dry, brittle mix.
	SUGGESTIONS:
	TO INCREASE FLOW:
	Limestone will increase flow.
	Less than 1% absorption of asphalt.
	Polishing aggregate due to nonfriction values.
	More crushed stone will increase flow.
High Air Voids	COMMENTS:
	It is important to decrease the air voids within a given limit even though the stability may be satisfactory. High air void content is associated with premature hardening of the asphalt and stripping. Stripping is a physical separation of the asphalt and aggregate.
	SUGGESTIONS:
	TO DECREASE THE AIR VOID CONTENT:

Change the grain size distribution by adding more mineral filler.

Increase the compaction temperature (within the specified range).

Make the mix denser (closer to the Fuller curve).

Low Air Voids

COMMENTS:

It is important to increase the air voids even when the stability is satisfactory. Low air voids may lead to flushing and instability.

Flushing

Flushing occurs when there are too few air void (or too much asphalt). With time, the asphalt concrete compacts. The asphalt cement squeezes out from between the aggregate particles making the pavement slick. The cure is to reduce the asphalt cement content or to increase the air voids.

Instability

Instability means the stability is low when the sample is loaded. This makes the sample easier to compact, therefore producing a tender mix. The mix becomes very unstable around 2 percent air voids. Rutting and shoving may occur. The mix will have no shear strength due to a lack of grain to grain contact.

SUGGESTIONS:

TO INCREASE THE AIR VOID CONTENT:

Change the grain size distribution (GSD) by adding more course or fine aggregate.

Reduce the asphalt cement content (This may also reduce the durability of the pavement, and may lead to brittleness, accelerated oxidation and increased permeability.)

Decrease the compaction temperature (within specified range).

Low Stability

COMMENTS:

Low stability guarantees problems, but high sta bility does not guarantee freedom from problems.

Changing the AC content will increase stability up to a point.

SUGGESTIONS:

TO INCREASE STABILITY -

Add more crushed material. The internal friction is usually higher in crushed material than in river-run material. Some aggregate, such as quartz, does not experience an increase in inter nal friction with increased number of broken faces.

Increase the maximum particle size.

Age pills a few days. This will increase oxidation of the asphalt.

Increase the specific gravity of the asphalt. This will decrease stripping potential, but will also reduce pavement life due to cracking.

Increase the fines content. Fines are particles that pass the #8 Sieve. They can be clay, mineral filler, sand, or dust. If clay is used to increase fines content, air voids are decreased. To preserve air voids, thickness must be decreased. This increases the oxidation rate and decreases durability. Some clay has a high absorption rate, therefore it may absorb some of the asphalt.

Mixes with too much natural sand tend to shove when compacted.

Dust is defined as particles that pass the #200 sieve.

High VMA COMMENTS:

Rounded particles tend to decrease VMA.

VMA is more a function of fine aggregates than gravel.

SUGGESTIONS:

TO DECREASE THE VOIDS MINERAL AGGREGATE -

If you have crushed aggregate, add round.

Increase maximum aggregate size.

Increase AC content.

Increase the mineral filler. Addition of mineral filler usually requires reduction of the asphalt cement content, to avoid flushing. If fly ash is to be used as mineral filler, 70% of it has to pass the #200 sieve.

After the advice is given, the program gives a summary of which parameters were too high, too low, or satisfactory. The program then concludes.

III. Suggestions for Further Work

HOTMIX! can be improved by the addition of the following features:

- a report generator will make the program more useful. This generator would provide a hard copy of the results and advice. If the generator was written with a program outside 1st Class HT, it could be made to incorporate the asphalt content graphs that appear in the final part of HOTMIX!,

- user-defined ranges for allowable gradations. At present, HOTMIX! only allows the user to select from three FHWA gradations. Allowing the user to input and store gradations would increase the utility of HOTMIX!,

- the addition of cost data on the aggregate blending screen. This will allow the user to optimize not only the gradation, but also the cost.

REFERENCES

1. ASTM D2041; 1990. ASTM; Philadelphia, PA.

2. State of Alabama Highway Department, 1985, "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects," FP-85.

3. National Center for Asphalt Technology Bulletin, 1989. "Maximum Density Line: Which One Should be Used?" Fall, p.6.

Acknowledgments

This project was sponsored by the Alabama Highway Research Center, at Auburn University. Dr. Frazier Parker, Director of the HRC, funded the project.

The following contributed expertise in developing HOTMIX!, and provided many useful suggestions in the operation of HOTMIX!:

Mr. Tommy Bender
Dr. Ray Brown
Mr. Doug Eiland
Mr. Eddie Eiland
Mr. Wayne Hubbard
Mr. Prithvi (Ken) Kandhal
Dr. Freddy Roberts
Mr. Floyd Strickland
Mr. Johnny Turner

Messrs. Todd Dukes, Brian Jones and Mark Saunders did an extensive part of the programming.

APPENDIX A

Viscosity-Graded Asphalt Cement Specification
ASTM D3381 TABLE 1
(used for NORMAL temperature pavements)

	AC 2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140F, P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275F, min, cST	80	110	150	210	300
Penetration 77F, 100g 5 s, min	200	120	70	40	20
Flash point, Cleveland open cup, min, F	325	350	425	450	450
Solubility in Trichloro-ethylene, min %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test: viscosity, 140F, max, P	1250	2500	5000	10000	20000
Ductility, 77F, 5cm/sec min, cm	100	100	50	20	10

note: if ductility is less than 100, material will be accepted of ductility at 60F is 100 minimum at a pull rate of 5 cm/sec.

APPENDIX B

Viscosity-Graded Asphalt Cement Specification
ASTM D3381 TABLE 2
(used for LOW temperature pavements, where cracking is a concern)

	AC 2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 140F, P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	3000 ± 600	4000 ± 800
Viscosity, 275F, min, cST	125	175	250	300	350	400
Penetration 77F, 100g 5 s, min	220	140	80	60	50	40
Flash point, Cleveland open cup, min, F	325	350	425	450	450	450
Solubility in Trichloro-ethylene, min %	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test: viscosity, 140F, max, P	1250	2500	5000	10000	15000	20000
Ductility, 77F, 5cm/sec min, cm	100	100	75	50	40	25

note: if ductility is less than 100, material will be accepted of ductility at 60F is 100 minimum at a pull rate of 5 cm/sec.

APPENDIX C

ASTM D 2041

Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures ("Rice Method") (abbreviated - does not cover pycnometer method)

1. SCOPE

1.1 This method covers the determination of the theoretical maximum specific gravity of uncompacted bituminous paving mixtures. The method also includes a rapid test version for relative specific gravity suitable for use in a field or plant laboratory.

2. APPLICABLE DOCUMENT

2.1 ASTM Standard:

D 979 Methods for Sampling Bituminous Paving Mixtures

3. DEFINITION

3.1 Specific gravity - as determined by this method, the ratio of the mass of a given volume of material at 25C (or stated temperature) to the mass of an equal volume of water at the same temperature.

4. APPARATUS

4.1 Container:

4.1.1 Four variations of the vacuum saturation technique using containers of different size and functional design are described. The container may be:

4.1.1.1 Type A - A glass, plastic, or metal bowl having a capacity of at least 1000 ml.

4.1.1.2 Type B - A volumetric flask having a capacity of at least 1000 ml.

4.1.1.3 Type C - An intermediate-size heavy wall glass pycnometer having a capacity of approximately 4000 ml.

or

4.1.1.4 Type D - A large-size plastic pycnometer having a capacity of at least 10,000 ml.

4.1.2 The container size depends on the minimum sample size requirements as given in 6.2.

4.1.3 Containers shall be sufficiently strong to withstand an essentially full vacuum and shall have covers as follows:

4.1.3.1 A cover fitted with a rubber gasket and a hose connection, for use with the bowl (Type A).

4.1.3.2 A rubber stopper with a hose connection, for use with the volumetric flask (Type B).

4.1.3.3 A suitable vacuum connection assembly consisting of a vacuum gage, release valve, and tubing connector, plus a tapered stopper device for maintaining consistent volume regulation, for use with the pycnometer (Type C or D).4.1.4 A small piece of fine wire mesh covering the hose opening will minimize the possibility of loss of fine material. Because of the mass involved, approximately 20 kg (44 lb), the large-size pycnometer container (Type D) should be equipped with suitable handles to facilitate transport and shaking while under vacuum to assist bubble release. Construction should permit visual observation of the effects of vacuum and shaking.

4.2 Balance, with ample capacity, and with sufficient sensitivity to enable the specific gravity of samples of uncompacted paving mixtures to be calculated to at least four significant figures; that is, to at least three decimal places. For the bowl method (Type A), the balance shall be equipped with a suitable suspension apparatus and holder to permit weighing the sample while suspended from the center of the scale pan of the balance.

4.3 Vacuum Pump or Water Aspirator, capable of evaluating air from the container to a residual pressure of 30 mm Hg (4.0 kPa) or less. A water aspirator or vacuum pump with less capability may be used for the rapid test version (Section 12).

4.4 Manometer or Vacuum Gage, suitable for measuring the specified vacuum.

4.5 Water Bath:

4.5.1 For Type A, B, or C containers, a constant-temperature water bath of suitable size for the container to be used. For Type D, the large-size plastic pycnometer, no water bath is required. 4.5.2 When using the weighing-in-water technique (7.4.1), a water bath suitable for immersion of the suspended container and deaerated sample is required.

4.6 Miscellaneous - A suitable trap (Erlenmeyer flask) installed in the line is recommended to prevent water from entering the vacuum pump. Also, use of a plastic twistcock valve in the line adjacent to the flask or pycnometer will minimize loss of water during shaking and provide quick disconnection in case of foaming or malfunction. For use with glass containers, a rubber or resilient plastic mat is required as a safety precaution to avoid impact on a hard surface while under vacuum.

6. SAMPLING

6.1 Obtain the sample in accordance with Method D979.

6.2 The size of the sample shall conform to the following requirements. Samples larger than the capacity of the container may be tested a portion at a time.

Size of Largest Particle of Sample Aggregate in Mixture, mm (in.)	Minimum Size, g
50.0(2)	6000
37.5 (1 1/2)	4000
25.4 (1)	2500
19.1 (3/4)	2000
12.5 (1/2)	1500
9.5 (3/8)	1000
4.75 (No. 4)	500

7. PROCEDURE

7.1 Separate the particles of the sample, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.4 mm (1/4 in.). If the mixture is not sufficiently soft to be separated manually, place it in a large, flat pan and warm in an oven only until it can be so handled. See also Section 12, for alternative handling possible with the large-size plastic pycnometer (Type D).

7.2 Cool the sample to room temperature, place in a container, and weigh. Designate the net mass of sample as A. Add sufficient water at approximately 25C (77F) to cover the sample. With the large-size plastic pycnometer (Type D), the sample does not have to be cooled and the added water at any convenient temperature may be brought up into the domed lid about halfway to minimize evacuation time.

7.3 Remove entrapped air by subjecting the contents to a partial vacuum, 30 mm Hg (4 kPa) or less absolute pressure, for 5 to 15 min (see Note 5). (A partial vacuum of 30 mm Hg (4 kPa) absolute pressure is approximately equivalent to 730 mm Hg or 28.7 in. Hg reading on a vacuum gage at sea level.) Agitate the container and contents either continuously by mechanical device or manually by vigorous shaking at intervals of about 2 min. Glass vessels should be handled on a resilient surface, such as a rubber or plastic mat, and not on a hard surface, to avoid impact while under vacuum. Vacuum should be applied and released gradually by using the bleed valve.

7.4 Immediately after removal of the entrapped air (7.3), proceed with one of the following determinations:

7.4.1 Weighing in Water - Suspend the bowl (Type A) or flask (Type B) and contents in the water bath and determine the mass after 10 min immersion. Measure the water bath temperature, and if different from 25 C (77 1.8F) in the water bath. Determine the mass of the container (and contents), completely filled in accordance with 5.2, 10 min after completing 7.3. Designate this mass as E.

7.4.3 Large-Size Plastic Pycnometer (Type D) Determination - Fill the pycnometer with water of approximately the same temperature as the contents, inset the vented stopper, and dry the outside using the same technique as in 5.3. The elapsed time for gently pouring in the final water and drying shall be the same as the calibration time within 1 min. Determine the mass of the pycnometer completely filled and designate this total mass as G. Remove the vented stopper and record the temperature of the water.

8. CALCULATION

8.1 Calculate the specific gravity of the sample as follows:

8.1.1 Weighing in Water:

$$\text{sp gr} = \frac{A}{A - C} \qquad (1)$$

where:

A = mass of dry sample in air, g, and
C = mass of sample in water, g.