CHAPTER 7

QUALITY CONTROL AND ACCEPTANCE OF HOT MIX ASPHALT

General

Hot mix asphalt (HMA) mixtures have traditionally been designed using an empirical approach to determine acceptable mix design criteria. Using this approach, mixtures were designed in the laboratory using a specific set of design criteria and were then produced in the field. The pavements constructed using these mixtures were evaluated over a period of time. The actual field performance was used as a guide to judge the adequacy of the original design criteria. If the pavements did not perform to the satisfaction of the agency, the mix design specifications were often adjusted in an attempt to overcome inadequacies in certain performance categories. Although these practices are clearly related, they are often considered separate activities.

The goal of mix design is to arrive at a starting point for establishing process mixing control and uniformity. This starting point is most often referred to as the job mix formula, or JMF. The JMF is the combination of aggregate and asphalt binder materials proposed for use on a project that when tested, using the required mix design procedures, yields results that meet all the established design criteria. For specific mix design procedures refer to the Asphalt Institute's *Mix Design Methods for Asphalt Concrete and Other Hot Mix Types* (MS-2), and *Superpave Mix Design* (SP-2).

It has been documented in many cases that even though a mix is designed for a certain percent of air voids in the laboratory, a plant-mixed sample containing the proper asphalt content, aggregate gradation and compacted by the same laboratory method may show different volumetric properties. The results of FHWA Demonstration Project 74 (Demo 74) indicated substantial differences may exist between the laboratory mix design and the volumetric properties of the field-produced mixture[1]. Most often these changes result in lower air void and VMA values than the target established for the JMF. Figures 7.01 and 7.02 show the differences in air voids and VMA found during the FHWA study.

Significant equipment and material differences exist between the small scale operation of the laboratory mixing bowl and an asphalt mixing facility, which could lead to the mixture property changes noted. Many causes for volumetric changes in field produced mix have been proposed:

- Moisture removed more effectively in the laboratory than in the field
- An excessive amount of baghouse fines returned to the mixing process.
- Highly absorptive aggregates used (field absorption may differ from laboratory absorption)
- Poor sampling used to obtain samples for the laboratory design
- Non-standard mix design procedures used to develop the JMF
- Material sources (location or strata) changed between the mix design and field production
- Aggregate degradation and shape changes during plant mixing.
- Non-uniform stockpiling of aggregates

The changes which occur in the field-produced mixture are likely due to a combination of some or all of the listed causes in any particular case. Attention to detail in material production and mix design development can reduce the potential effects of many of the factors shown.

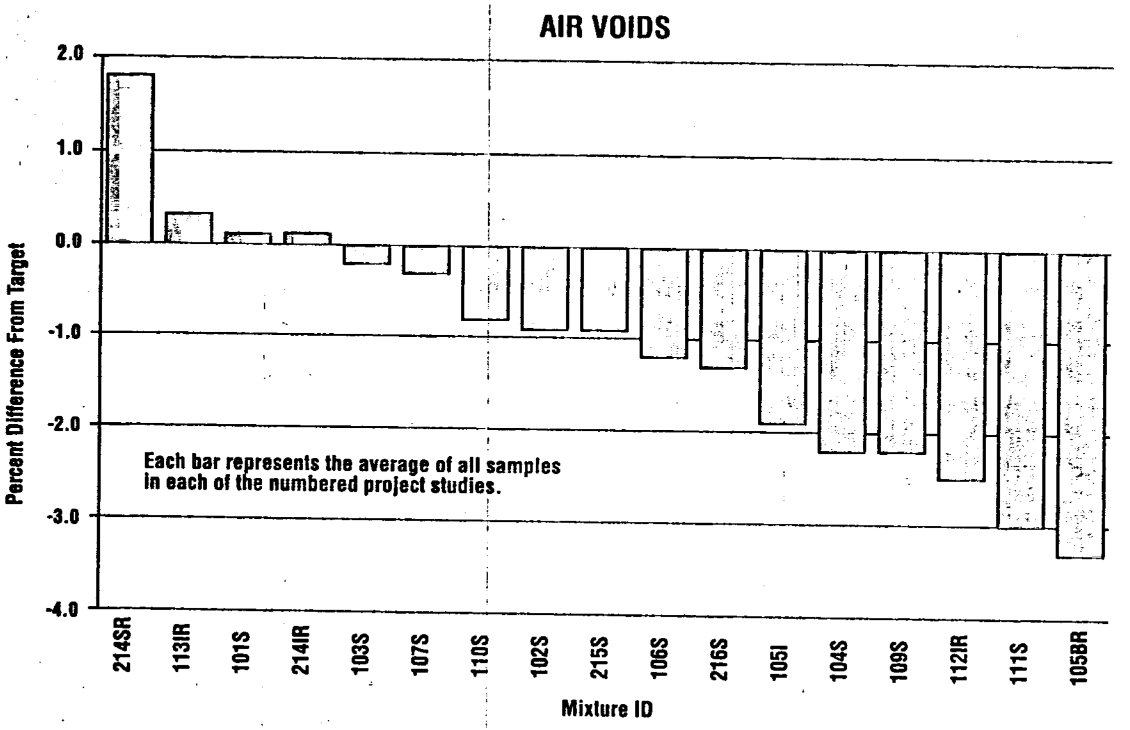

Figure 7.01 Percent Difference in Air Voids From Target Value

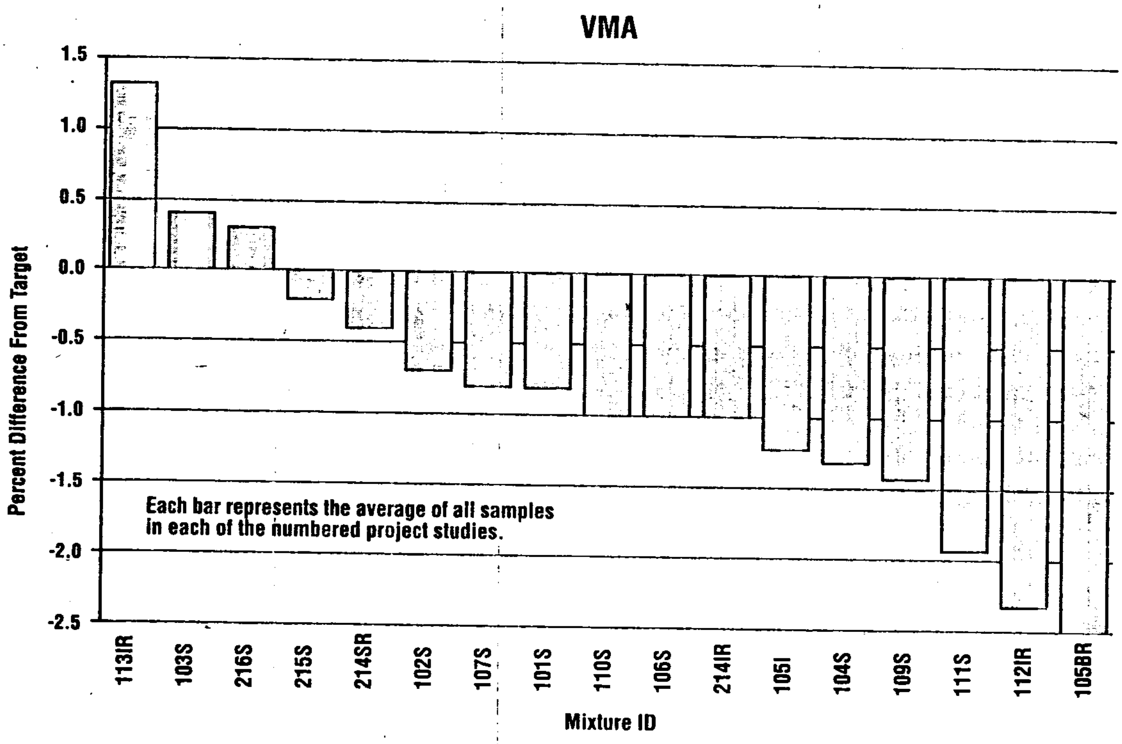

Figure 7.02 Percent Difference in Voids in the Mineral Aggregate From Target Value

Table 7.01 Mix Design Verification Results by Mix Number and Designer

Study Number	Mix Designer	Mix Verification Result
101S	Contractor	Go With Changes
102S	Contractor	Go With Changes
103S	Contractor	Go With Changes
104S	State	Redesign
105BR	State	Redesign
105I	State	Redesign
106S	State	Go With Changes
107I	Contractor	Go With Changes
109I	State	Redesign
110S	State	Go With Changes
111S	State	Redesign
1121R	State	Go With Changes
1131R	State	Go With Changes
214SR	Contractor	Go As Is
214R	Contractor	Go As Is
215S	State	Go With Changes
216S	State	Go With Changes

The Demo 74 study also provided information related to the responsible laboratory for developing the initial JMF for the mixtures tested. Table 7.01 shows which mixtures were designed by the state highway agency and those designed by the contractor's laboratory. Changes between laboratory mix design and field-produced mixtures were needed when designed by either responsible party. However, there were no instances where redesign of the mixture was recommended when the contractor had developed the JMF. This suggests that the contractors involved in this study had a good understanding of the materials they used and how to control the volumetric properties of the mixture during production.

With these factors in mind, adjustments can be made by the contractor in the mix design process to accommodate these anticipated changes. For example, if a contractor knows through experience that using a combination of aggregates from certain sources typically results in the return of 1% baghouse fines to the mix during production, this amount of baghouse fines could be incorporated into the aggregate blend during the mix design. By doing this, the volumetric changes from the laboratory design to the field-produced mix could be reduced. A number of other factors contributing to volumetric changes may be known to the contractor. These could also be accounted for during the mix design. It is not reasonable to assume the state agency laboratory personnel would be aware of all the possible factors to consider for all the possible combinations of materials and asphalt mixing plants. Therefore, it is recommended that contractors be responsible for providing acceptable mix designs to the contracting agency prior to mix production.

Field verification of the HMA design is the initial phase of the overall Quality Control (QC) process. It involves testing and analyzing the field-produced mixture to ensure that the criteria established by the specifying agency for the particular mixture are being met. Verification is necessary at the beginning of production of each mix or JMF to measure what differences, if any, exist and what corrective measures need to be taken.

Table 7.02 Sample Quality Control and Acceptance Procedures

- I. **Pre-production Sampling and Testing**
  - A. Aggregate for mix design
  - B. Mineral filler/additives, if necessary
  - C. Asphalt material from proposed source
- II. **Job Mix Formula Approval and Verification**
  - A. Aggregate gradation
  - B. Aggregate physical properties where required
  - C. Asphalt Content
  - D. Air voids, VMA and VFA
  - E. Stability/Strength testing, where applicable
  - F. Moisture susceptibility testing
- III. **Quality Control Testing During Production by Contractor**
  - A. Maximum theoretical specific gravity (Rice)
  - B. Bulk specific gravity for air voids, VMA and VFA
  - C. Aggregate gradation
  - D. Asphalt content
- IV. **Production or In-place Acceptance Testing by Agency**
  - A. Asphalt content
  - B. Aggregate gradation
  - C. Air voids, VMA and VFA
  - D. In-place density
  - E. Thickness
  - F. Smoothness/Ride Quality
  - G. Roadway profile

Quality control is one part of a total quality assurance system designed to assure that the quality of the construction and materials conform with the plans and specifications under which it was produced. Activities that occur under the umbrella of this total system are:

- Quality control practices by the contractor designed to monitor the product manufacturing process.
- Acceptance sampling, testing and inspection by the agency to determine if satisfactory quality control has been exercised to attain proper specification compliance
- Independent assurance sampling and testing. This third party involvement is used to provide an independent critique of the entire QA process. Sample quality control and acceptance procedures are shown in Table 7.02.

Field verification is intended to verify that plant production will essentially match the JMF. It often includes increased testing above the minimum specified frequency and can result in adjustments to the JMF or in a complete redesign of the mixture.

A properly designed and administered quality control program for HMA is meant to prevent the production of substandard or out-of-specification material rather than to document the degree of noncompliance after the fact. An adequate quality control process will address the concerns and risks of both the producer and the purchasing agency. The process will provide the producer with confidence and evidence of the product quality, the ability to discern trends in production and anticipate potential problems, and the ability to assess the risk of producing noncompliant materials. The agency will be provided assurance that the materials being produced are within the established criteria, which should result in the desired pavement performance.

Quality Control Testing

Specific properties of the field-produced mixture are measured and compared to the job mix formula and other specification requirements. The quality control (QC) tests that are used will vary depending on the design procedure specified by the controlling agency. Until recently, most organizations that incorporate quality control have used the Marshall mix design method primarily because the compaction equipment is portable, making it economical for quality control techniques. Texas gyratory compaction is also well suited. Since the end of the Strategic Highway Research Program (SHRP), the Superpave system has been used with increasing frequency for mix design and field quality control activities. The Superpave Gyratory Compactor (SGC) was designed for use as a field control compactor as well as for mix design. For information related to the Superpave system refer to the Asphalt Institute's *Superpave Mix Design* (SP-2).

While some tests used in the quality control process are governed by strict test methods, others have more than one alternative option. For a quality control program to operate properly, it is essential that all those involved in the testing activities use standard testing equipment and established testing procedures. When standardization of the equipment and procedures is not employed throughout the quality control process, an increase in test variability will likely occur. This increases the probability that poor materials could be accepted or that quality materials could be rejected.

Figure 7.03 shows the amount of sample variance attributable to each of three factors for the given test. One of the primary goals of a quality control program should be to reduce as much

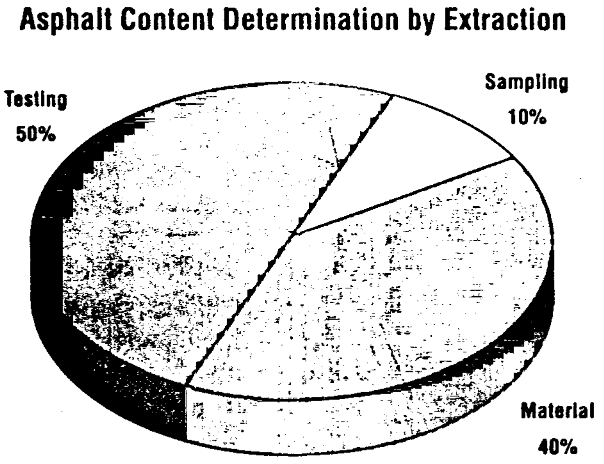

Figure 7.03 Percent of Total Sample Variance Attributable to Factors Shown

as possible the sampling and testing contributions to the total variance in test results. The allowable variance is generally taken into consideration by providing acceptable plus and minus tolerances to the JMF target values.

Many agencies and industry partners have incorporated technician training and certification programs into the quality assurance process. Both agency and contractor personnel should go through the same training program to ensure all those involved with field quality control and acceptance understand their responsibilities and are qualified to perform their assigned duties. These training activities also address the equipment and procedural requirements of the program.

A standard specification has been established by ASTM to address the testing laboratory and technician capabilities in performing tests on bituminous materials. ASTM D3666, "Minimum Requirements for Agencies Testing and Inspecting Bituminous Paving Materials", discusses the criteria which can be used to evaluate the qualifications of an agency, consultant or contractor laboratory for performing tests on HMA materials. This standard can be consulted when establishing a quality control program.

The following sections discuss the tests used to verify, and subsequently control the mixture's compliance with the job mix formula.

➤➤Asphalt Content

Many methods can be used to determine the asphalt content of HMA mixtures. The most frequently used method to date is the extraction test, which separates the asphalt and aggregate using a solvent (AASHTO T164; ASTM D2172). This process results in the ability to perform a gradation analysis on the aggregates after the asphalt binder has been removed. "Automatic recordation" can be used during mix production to calculate asphalt content, if the asphalt mixing facility makes detailed measurements of the materials used. Properly calibrated nuclear asphalt content gauges can provide measurements of asphalt content on the produced mixture (AASHTO T287; ASTM D4125), but since the asphalt is not removed, gradation analysis cannot be performed. These gauges grew in popularity due to environmental constraints being placed on the chlorinated solvents commonly used in extraction testing. Asphalt content determination by the ignition method has been increasing in use in recent years. The ignition method uses very high temperatures ±538°C (1000°F) to "burn off" the asphalt binder from the mixture sample. This method also requires that a calibration be performed on the aggregates used in the mixture to account for possible aggregate degradation during the testing process. Due to the potential for aggregate gradation changes to occur during this test, caution is recommended when using the remaining aggregates for gradation compliance testing.

➤➤Aggregate Gradation

Various ways also exist to determine aggregate gradation. The aggregate cold feed belt or hot bins are sometimes sampled prior to mixing with asphalt. However, testing of the plant-mixed material after extraction or ignition is the only true measurement of the aggregate gradation in the final mixture. Depending on specific aggregate properties, it is not uncommon during production for an additional one half to one and one half percent of minus 0.075 mm (No. 200) material to be returned to the mix from a baghouse emission control system. A wet scrubber system may reduce the amount of fines in the mix by an equal amount. In addition, degradation of the aggregates may occur in the drying and mixing process in a drum mix plant. These changes will not be realized if gradation testing is not performed on aggregate from the plant-mixed material. This amount of change in the fines content of the mixture can have a profound effect on the mixture volumetrics.

➤➤*Maximum Specific Gravity*

The theoretical maximum specific gravity, G_{mm}, of the bituminous paving mixture (AASHTO T 209; ASTM D 2041) is a key measurement during both laboratory mix design and quality control procedures. Multiplying the G_{mm} by the unit weight of water, (γ_w, will yield the theoretical maximum density of an asphalt mixture. This is the density of the paving mixture in a "zero air voids" condition. Also called the "Rice" specific gravity after its developer, G_{mm} is the ratio of the weight in air of a unit volume of a voidless asphalt binder and aggregate mixture to the weight of an equal volume of water, at a known temperature. Using a partial vacuum procedure to remove entrapped air from a loose mixture, the test determines the volume of the asphalt mix in a voidless state. The weight of the mix sample divided by this volume is the maximum specific gravity of the mixture.

EXAMPLE 1

Theoretical maximum specific gravity; G_{mm} = 2.438
Unit weight of water = (γ_w = 1,000 kg/m³ (62.4 lbs/ft³)

Maximum density = G_{mm} x (γ_w = 2.438 x 1,000 (62.4) = 2,438 kg/m³ (152.1 lbs/ft³)

The theoretical maximum specific gravity is used to calculate the percent air voids of laboratory compacted samples. The maximum theoretical density is used to calculate the relative density of field compacted pavement cores. The relative density referred to is the ratio of the density of the pavement cores to the maximum theoretical density, not to the laboratory density of compacted mixture samples.

When conducting asphalt mix designs, and testing the mixture properties in the field, it is essential to take asphalt absorption into account. The amount of asphalt absorbed into the aggregates during production, paving and compaction of the mixture will be a function of several factors:

- Absorption characteristics of the individual aggregates and the aggregate blend
- Temperature of the mixture
- Amount of time mixture is maintained at elevated temperatures

It is difficult to determine the amount of asphalt absorption that will ultimately occur in the roadway through laboratory testing. Estimations can be obtained through experience with specific aggregates and knowing the water absorption characteristics of the materials. However, it has been demonstrated that the G_{mm} value changes as the asphalt absorbed into the aggregate varies with a given mixture. This can be explained by recalling the weight/volume relationship of material when determining its theoretical maximum specific gravity.

Immediately after mixing a sample of HMA, using known weights of aggregate and asphalt binder, the volume of the uncompacted mixture can be determined using the Rice test mentioned above. We could assume that a certain amount of asphalt absorption had taken place during this procedure. If the mixture is held at a high temperature for a longer period of time after mixing, the asphalt binder will continue to be absorbed into the pores in the aggregate. The assumption could also be made in this instance that the relative absorption would be greater than in the first case. The weight of materials remains constant from one example to the other. However, as the asphalt absorption increases, the overall volume of the mixture sample

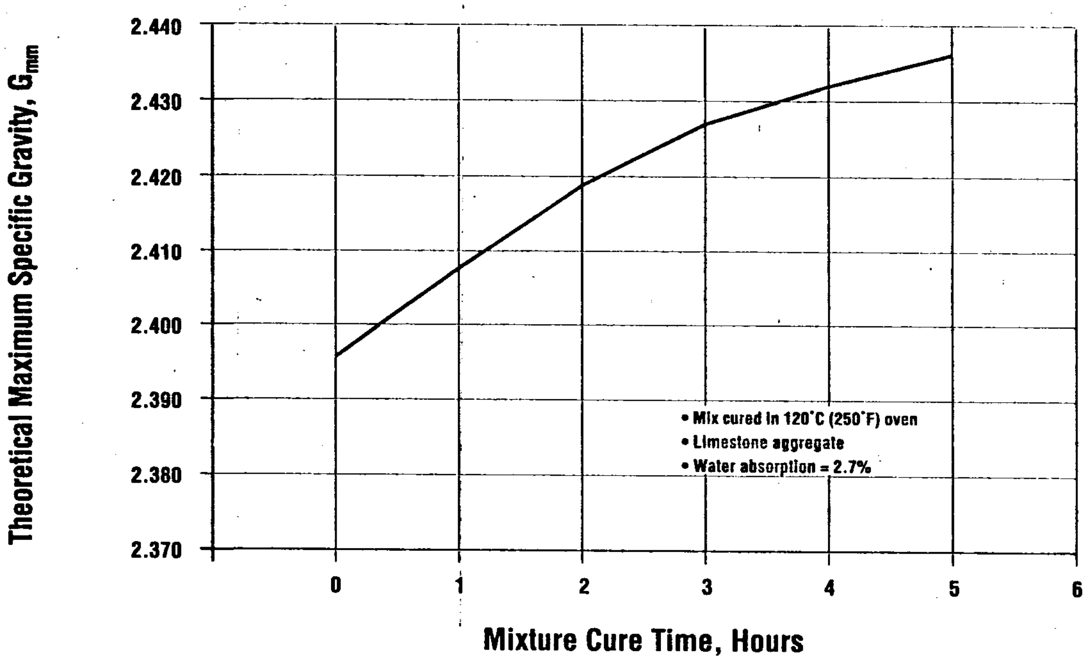

Figure 7.04 Curing Time Influence on G_{mm} Determination[3]

decreases. This results in a higher G_{mm} value relative to the first test result. For highly absorptive aggregates, this potential variability in the G_{mm} value is greater than with aggregates having lower absorption characteristics. Figure 7.04 shows the effect of cure time on G_{mm} test results for a particular aggregate blend.

It is important to maintain elevated temperatures in quality control testing as close as possible to the amount of time used for development of the mix design. This mix design consideration is often referred to as "curing" the mixture. Many agencies have developed standard curing times between two and four hours for mix design practices. To avoid using improper G_{mm} values for quality control decisions, it is recommended the same curing time be used for field testing.

➤➤Bulk Specific Gravity

A sample of the plant-produced mixture is cured and compacted using the same procedure used in the mix design (such as a specific number of Marshall hammer blows or number of gyrations). The compacted sample is then used to determine the bulk specific gravity, G_{mb}, of the hot mix asphalt (AASHTO T 166 or T 275; ASTM D 1188 or D 2726). Multiplying the G_{mb} by the unit weight of water will yield the bulk density of the compacted sample.

EXAMPLE 2

Bulk specific gravity = G_{mb} = 2.344
Unit weight of water = (γ_w = 1,000 kg/m^3 (62.4 lbs/ft^3)

Bulk density = G_{mb} x (γ_w = 2.344 x 1,000 (62.4) = 2,344 kg/m^3 (146.3 lbs/ft^3)

➤➤Air Voids

Since G_{mb} is measured on the compacted mixture specimen, the measured volume includes air contained within the sample. The percent air voids, V_a, of the compacted mixture is expressed as a percentage of the total bulk volume of the sample and is calculated using the bulk and maximum theoretical specific gravity in this equation (AASHTO T 269, ASTM D 3203):

$$V_a = [(G_{mm} - G_{mb})/G_{mm}] \times 100$$

EXAMPLE 3

$G_{mm} = 2.438$ $G_{mb} = 2.344$

$$V_a = \frac{(2.438 - 2.344)}{2.438} \times 100 = 3.9 \text{ percent}$$

EXAMPLE 4

Assume the G_{mm} value used in Example 3 was determined after a curing period of three hours. Also assume that after the same mixture was cured for a period of one hour a G_{mm} value of 2.419 is obtained. The G_{mb} of 2.344 is the same in both examples.

$$V_a = \frac{(2.419 - 2.344)}{2.419} \times 100 = 3.1 \text{ percent}$$

The difference in the air void calculation between Examples 3 and 4 illustrates the importance of allowing the mixture to cure in the field for the same period of time as in the mix design. An air void result of 3.1% might cause the QC supervisor on a project to reduce the asphalt content to raise the air voids to a production target of 4%. However, by not accounting for the continuing asphalt absorption taking place, the result would yield a mixture with an asphalt binder content which is too low for this particular mixture.

➤➤Stability and Flow

Marshall stability and flow properties can be measured on the laboratory compacted samples of field-produced material, and some agencies include them in their quality control testing requirements. However, the reliability of stability and flow as quality control tests is less than density/voids analyses, since Marshall stability and flow values are affected by many different aggregate and asphalt properties. The values obtained are not necessarily an indication of adequate mixture performance. The engineering properties of asphalt mixtures are better defined by the volumetric proportions of asphalt binder, aggregate and air contained within the compacted mixture. It is believed that if the volumetric properties of air voids and VMA, along with the asphalt content and gradation, of the mixture are properly controlled, then stability and flow will correspondingly meet the appropriate specifications.

0.74	0.60	0.01	0.27	0.43	0.29	0.21
0.78	0.11	0.65	0.20	0.98	0.34	0.83
0.87	0.64	0.50	0.14	0.09	0.71	0.41

Figure 7.05 Example Excerpt From a Random Number Table

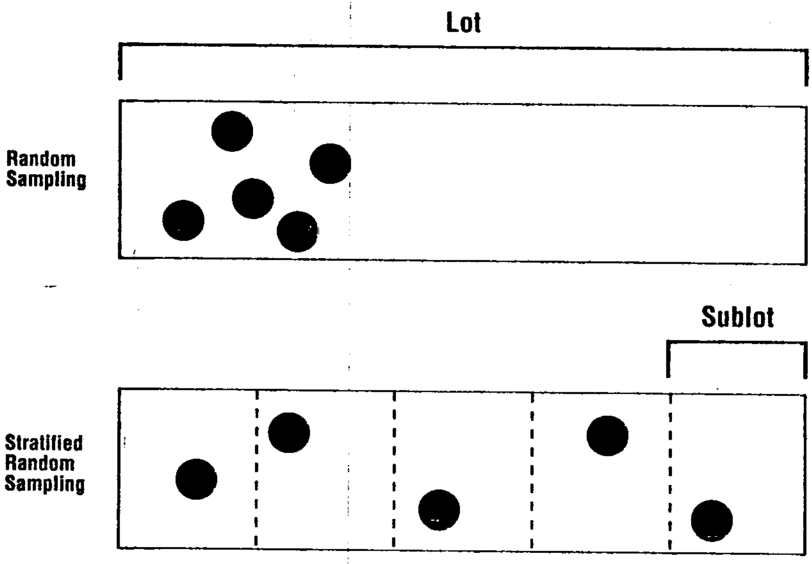

Figure 7.06 Random Sampling vs. Stratified Random Sampling a Material Lot

Sampling and Testing Plan for Quality Control

For a quality control program to be successful, the samples obtained for testing must be representative of all the materials produced for the production run. Samples must be taken often enough to ensure that the material is being produced uniformly throughout the entire production process. For quality control testing of hot mix asphalt, samples are taken at designated intervals. The actual sampling interval, referred to as the sampling frequency, will depend on plant production rates and overall project size.

Typical quality assurance sampling and testing programs use a random sampling procedure to identify where and/or when samples are obtained for testing. A truly random sampling process ensures that any specific increment of a quantity of material has an equal probability of being selected. Random sampling also means that no bias is introduced into the selection process. An effort to include some obviously deficient or passing materials would not constitute a random process.

The most commonly used method of obtaining random samples is by using a random number table (see Appendix C). The table is entered by some predetermined means which is also random in nature. The required group of numbers can be selected by any process. From the starting point, rows or columns could be chosen. Alternate numbers or consecutive numbers can be chosen. Any desired format can be used to select the group of numbers needed. Computers, and some calculators, can also be used to generate random numbers. Figure 7.05 shows an example of an excerpt from a random number table.

The production of HMA is divided into segments of relatively large size which are tested for specification compliance. These large quantities are referred to as a "lot." A lot can be defined as a measured amount of material assumed to be produced by the same process. Sampling of construction materials can be based on divisions of time, area paved, distance paved, weight produced (tonnage), compacted volume or any other suitable increment. For purposes of discussion, assume the lot is based on tonnage of HMA. A lot is often the total tonnage of a single day's mixture production or a specific tonnage of material. Since it is not practical to test every metric ton (ton) of material in the lot, samples are chosen and tested which are assumed to represent the entire lot of material. This would only be true if the process through which the HMA was produced was consistent from the start to the end of the lot.

Since random sampling procedures provide for an equal chance of any increment in a given lot being selected, the possibility exists that all samples taken may be grouped tightly together. For example, if 5000 metric tons (5500 tons) of HMA comprise a lot, it is possible that all samples could be obtained from the first 2000 metric tons (2200 tons) produced. The assumption could be made that the test results obtained represent the total lot tonnage. However, it is desirable to distribute the sampling process throughout the entire lot.

This is accomplished by dividing the lot into equal divisions and randomly selecting locations within these divisions for testing. These smaller divisions are referred to as sublots. In the previous example, the 5000 metric tons (5500 ton) lot could be divided into five equal sublots of 1000 metric tons (1100 tons) each. The random sampling process would then be used to sample each of the successive sublots of material. This process ensures that the sampling and testing is being "spread out" over the entire lot.

The process of dividing the lot into equal divisions and randomizing sample locations inside these sublots is termed a "Stratified Random Sampling" process. The sampling schedule for a particular project would define the quantity of material included in the sublots, as well as the lots. Figure 7.06 illustrates the two possibilities. The top half of the figure shows the possible result if the entire lot were sampled on a random basis. Note the tight grouping of the samples at the beginning of the lot. The second half of the figure shows the stratified sampling procedure resulting in more evenly distributed sample locations.

EXAMPLE 5

Your project specifies that a lot of HMA consists of all the tonnage produced in a single day. The projected total is 5000 metric tons (5500 tons) for the day. Specifications also require the lot to be divided into equal sublots of 1000 metric tons (1100 tons) each. Using the excerpt from a random number table in figure 7.05, determine the sampling locations for the day's production. (Your random number procedure has placed you at the upper left corner of the portion of the table shown, and it specifies that you move horizontally to the right.)

Total number of sublots required = 5000/1000 = 5 sublots

Five random numbers are needed. The numbers chosen are: 0.74, 0.60, 0.01, 0.27 and 0.43

Sublot		**Sample Metric Ton (Ton)**
#1: (0-1000 metric tons)	1000 x 0.74 = 740	740 (814)
#2: (1001-2000 metric tons)	1000 x 0.60 = 600 + 1000 = 1600	1600 (1760)
#3: (2001-3000 metric tons)	1000 x 0.01 = 10 + 2000 = 2010	2010 (2211)
#4: (3001-4000 metric tons)	1000 x 0.27 = 270 + 3000 = 3270	3270 (3597)
#5: (4001-5000 metric tons)	1000 x 0.43 = 430 + 4000 = 4430	4430 (4873)

It would be impractical to expect that the exact calculated ton of material would be sampled in the above example. It is relatively easy to determine which truck load of mix contains the "sample ton" through review of the weigh tickets provided at the plant. The calculated "sample ton" would be taken from the materials contained in that specific truck either out of the truck box itself, behind the paver, from the paver hopper or another location as indicated in the sampling and testing plan.

EXAMPLE 6

The same project in Example 5 also requires density testing on cores taken from the compacted pavement. Assume that the length of the pavement constructed is to be divided into five equal areas (sublots) for density testing. The total length of roadway paved for the day (one lot) was 10370 meters (34000 feet). The pavement width is 3.6 meters (12 feet), and a single lane was paved. Using the same random number procedure as above for rows two and three in figure 7.05, determine the longitudinal distance from the start of paving and offset from centerline of the cores.

The total length paved = 10370 meters (34000 feet)
Sublot length = 10370/5 = 2074 meters (6800 feet)
Longitudinal distance random numbers (row 2) = 0.78, 0.11, 0.65, 0.20, and 0.98
Centerline offset random numbers (row 3) = 0.87, 0.64, 0.50, 0.14 and 0.09

Core #1: (0 to 2074 m from start of paving)
Distance = 2074 x 0.78 = 1618
Centerline offset = 3.6 x 0.87 = 3.1

1618 m (5307 ft) from start
Offset = 3.1 m (10.2 ft)

Core #2: (2074 to 4148 m from start of paving)
Distance = 2074 x 0.11 = 228 228 +2074 = 2302
Centerline offset = 3.6 x 0.64 = 2.3

2302 m (7552 ft) from start
Offset = 2.3 m (7.5 ft)

Core #3: (4148 to 6222 m from start of paving)
Distance = 2074 x 0.65 = 1348 1348 + 4148 = 5496
Centerline offset = 3.6 x 0.50 = 1.8

5496 m (18030 ft) from start
Offset = 1.8 m (5.9 ft)

Core #4: (6222 to 8296 m from start of paving)
Distance = 2074 x 0.20 = 415 415 + 6222 = 6637
Centerline offset = 3.6 x 0.14 = 0.5

6637 m (21775 ft) from start
Offset = 0.5 m (1.6 ft)

Core #5: (8296 to 10370 m from start of paving)
Distance = 2074 x 0.98 = 2033 2033 +8296 = 10329
Centerline offset = 3.6 x 0.09 = 0.3

10329 m (33887 ft) from start
Offset = 0.3 m (1.0 ft)

ASTM D3665, *Standard Practice for Random Sampling of Construction Materials*, provides information and procedures for obtaining unbiased material samples. This standard can easily be adopted for use in sampling HMA mixtures. Random number tables are also provided in this standard.

Data Analysis Quality control involves two different levels of analysis performed on the HMA. The first involves field verification, the analysis of the mixture on the first day or two of full production, to compare the mixture to the job mix formula. The second uses day-to-day quality control tests performed to determine if the mixture properties have exceeded production tolerance limits.

➤➤Job Mix Formula Verification

At the beginning of production, asphalt content, gradation, and mixture volumetric analysis tests are performed to compare field-produced mixture properties with the job mix formula. These tests will indicate if the aggregate characteristics have varied from those used in the mix design, and may indicate if problems exist from possible changes in the aggregate after processing through the dryer.

At this point, the field verification results may show that changes in the mixing process are necessary to meet the job mix formula. For example, minor changes in the asphalt content may bring a mixture back within the tolerances of the volumetric requirements. Alternatively, if the mixture is meeting overall agency specifications but not the mix design targets, the job mix formula can be adjusted to accept these new targets. Finally, any dramatic differences between the laboratory design and field-produced mixture may necessitate a new mix design using the actual production materials.

➤➤Quality Control Testing

Once the job mix formula has been verified, daily quality control testing can provide an early warning of potential problems by indicating if the mixture properties are near the specification limits or deviate from the specifications. This daily testing is a part of plant process control that can identify potential problems before many tons of mix have been placed in the field.

Daily quality control test values are plotted on control charts. Continuous plots of mix data such as percent air voids, VMA, asphalt content, and aggregate percentages passing certain sieves such as 4.75 mm, 0.600 mm and 0.075 mm (No. 4, No. 30, and No. 200) provide a graphical representation of the production process. Target values and upper and lower control limits are set for each material property. The target value is the value specified by the job mix formula or the appropriate specification criterion, and the upper and lower control limits are the job mix formula or specification value plus and minus the allowable tolerance, respectively. The production values plotted in relation to these limits can be used to analyze the results of mixture production and make necessary adjustments to keep the production process within specification limits.

Figure 7.07 shows a set of control charts of asphalt content during production. The top chart shows the value of each asphalt content test performed. The bottom chart shows the moving, or running average of the asphalt content data. The moving average is calculated from consecutive tests values, typically three to five values per subgroup. After each test is performed, the new test value replaces the oldest test value in the subgroup to calculate the new moving

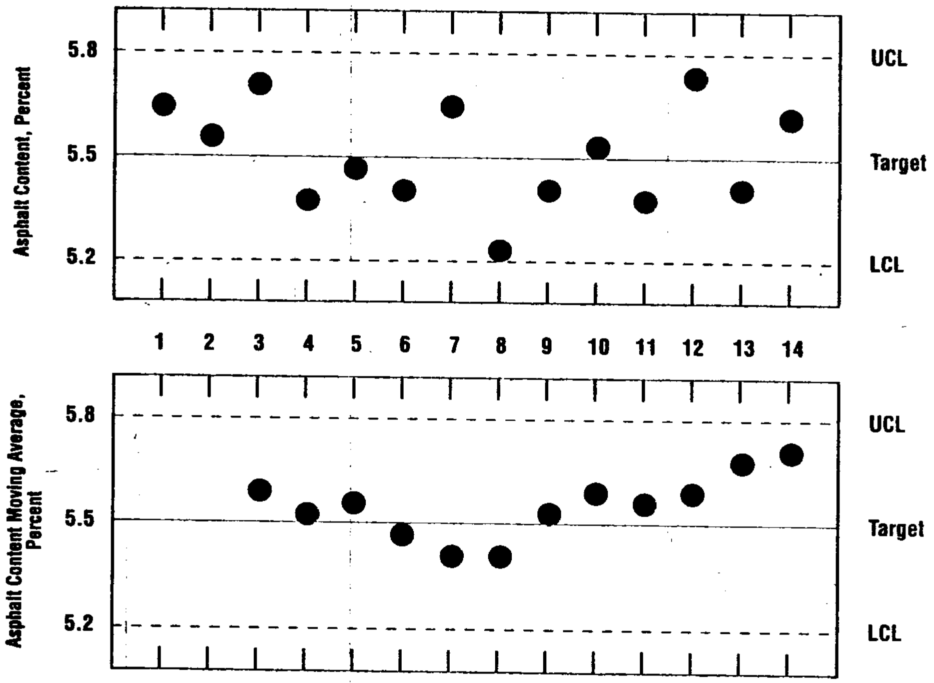

Figure 7.07 Typical Quality Control Charts During Mixture Production

average. A line is typically drawn to connect the points on the chart. The moving average values can be plotted on a separate chart or on the same chart as the individual test values. If the two are plotted on the same chart, a different colored line would normally be used to connect the test values. For example, a black line could be used to connect the values for the individual test results and a red line for the moving average values.

When analyzing quality control data, it is important to recognize sources of variation in the data. These sources include variation in the testing and sampling procedures, normal variations in the materials and production process, and variations due to problems in production. Following the testing and sampling procedures exactly as specified, and as presented in the appropriate training program, will help minimize this variation. Obviously, adjusting the production process on the basis of erroneous test results is not desirable.

The control charts can help differentiate between variation inherent in the material and production variation. They can also provide early signals of potential problems needing attention. The test data should be dispersed randomly about the target value and between the control limits. A few possible indications of existing or upcoming problems are:

- Values consistently higher or lower than the target
- Gradual or erratic shifts in the data
- Systematic cycling of the data

The moving average control chart in Figure 7.07 provides an indication of the overall "trend" of the process. It would be more reasonable to react to the process trend as opposed to making decisions based on individual test results. From point 11 to 14 there is an apparent trend for the average asphalt content of the mixture toward the upper end of the specification range. If this trend were to continue, the HMA supplier runs the risk of producing non-specified materials. This trend would indicate the need for some adjustment in the process to move toward the target asphalt content.

Acceptance Criteria

The particular criteria by which HMA construction projects are accepted depend on the type of specifications used for the project. There are various types of specifications in use, or being proposed, which emphasize different control parameters. They are:

- Method, or recipe specifications
- End result specifications
- Quality assurance specifications
- Performance based specifications

Method specifications spell out specifically the things or procedures that are used in the construction process. Equipment types and quantity, materials criteria such as aggregate gradations, method of construction such as number of roller passes, and other items, very closely control the construction process.

End result specifications move away from controlling the process of construction and concentrate more heavily on the testing of the mixture and pavement after completion for specification conformance. With this type of specification it is critical that the criteria used to judge the test results be adequate for pavement performance.

Quality assurance specifications are based on statistical sampling and testing performed by the contractor and the purchasing agency. Quality control procedures conducted by the contractor are used to assure the specifications are being met throughout the process. Acceptance sampling and testing, performed by the agency, checks the contractor's QC process and determines if the materials should be accepted. Independent assurance sampling and testing is performed by a third party to make sure the entire process is performing adequately. This is typically required only on federal aid projects but may be specified by other agencies.

Performance based specifications emphasize performance of the finished product over time and do not concentrate on construction activities. Specific performance criteria are established in the specification which the finished roadway must meet over a specified length of time. Warranty specifications would fall under this category. In addition, specifications which use performance related tests to evaluate the ability of a mix to perform as intended over a period of time are considered to be performance based specifications.

➤➤ Traditional Acceptance Plans

Acceptance criteria are usually based on a number of specific properties of the mixture and the finished pavement. Traditionally, the following set of items were used to evaluate HMA construction projects.

- *Materials* – Aggregate gradation & quality, asphalt binder properties, asphalt content and mixture volumetric properties
- *Thickness tolerances* – Cores, yield checks, string line or paver skis
- *Pavement smoothness* – Straight edge, profilograph or profilometer
- *Pavement density* – Cores and nuclear gauge readings

For many years, much of the responsibility for the traditional methods of acceptance was held by the specifying agency. Contractors often times submitted proposed aggregate and asphalt materials to the agency, which would then perform a mix design. At the start of production, the agency would conduct asphalt content tests and aggregate gradations to make sure the job mix formula was being duplicated within allowable tolerances. As long as the job mix formula was adhered to, the assumption was made that the mixture volumetric criteria were also being met. As stated earlier, this was often times a mistaken assumption.

This type of combined process control and acceptance also required the agency to be responsible for making adjustments to the aggregate proportions and/or the asphalt content of the mixture. By changing the mixture proportions at the plant, the agency actions would potentially have a direct effect on the contractor's ability to achieve density in the finished pavement. Often times penalties were assessed to the contractor for low densities and the contractor was not in a position to be able to make changes to the mixture to remedy the situation.

For these and other reasons, process control has been incorporated into the quality assurance type of specifications. Here the contractor is more in control of the finished product. Changes made at the asphalt plant which affect the placement and compaction operations are made by the contractor.

➤➤ Volumetric Mixture Control

The recent trend toward a quality assurance type of specification has emphasized mixture volumetric properties rather than the combination of individual material components. Mix design methods used today focus on volumetric properties such as air voids, VMA and voids filled with asphalt. These properties are much better indicators of the engineering properties of the mixture than are asphalt content and aggregate gradation.

These volumetric properties must be controlled in the field as well as be established in the mix design. Nevertheless, gradation and asphalt content determinations are also important to enable educated adjustments to the production process. Judgments on the quality of the finished product which are based on volumetric properties will lead to greater performance of the pavement.

The quality of the finished pavement is not entirely based on mixture properties. The density of the roadway after construction plays a major role in the overall performance of the roadway.

Density Specifications

Quality control of the HMA involves testing and analyzing the field-produced mixture to ensure that the mix design criteria established for the particular mixture are being met. In most cases, pavement density specifications are used to judge the acceptability of the compaction process during construction.

The goal of compacting a hot mix asphalt pavement is to achieve an optimum air void content and provide a smooth, uniform surface. The resultant, in-place air void content of the HMA is probably the single most important factor that affects performance of the mixture throughout the life of the pavement.

The activities involved with the proper design, production, placement, and compaction of the asphalt mixture are all combined to achieve the in-place density of the HMA pavement and ultimately determine whether the pavement will perform as expected. The density specifications to which the pavement is built are used to stipulate the acceptable level of compaction achieved.

A typical density specification represents a comparison between the in-place density of the pavement that is achieved after final compaction, and a reference density. One of three reference densities is typically used in density specifications: Laboratory density; maximum theoretical density; or control strip density. Use of the maximum theoretical density to determine HMA pavement density compliance is preferred by the Asphalt Institute.

➤➤*Laboratory Density*

This method compares in-place density to a laboratory-compacted sample of field-produced asphalt mix, and is particularly applicable to Marshall compaction procedures. The Superpave method of mix design uses the Superpave Gyratory Compactor (SGC) for laboratory compaction. It has been shown that the SGC procedure is also a method which is well adapted to field laboratory compaction operations. With either method, a reference density is established to which the density of the compacted pavement is compared. The field-produced HMA is compacted using the same compactive effort used during the mix design (e.g. 50 or 75 blows for Marshall compaction or design number of gyrations with the SGC) and the laboratory density is measured using the bulk specific gravity test.

In terms of specification compliance, an agency compares the in-place core density, or nuclear density readings, to the reference density in the form of a ratio:

$$\text{Percent of Laboratory Density} = \frac{\text{In-Place Density} \times 100}{\text{Laboratory Density}}$$

When it has been verified that the field-produced mix matches the mix design volumetric properties, the laboratory compacted samples should provide the same air void content used in the mix design. This is typically four percent. If an in-place air void content of 8 percent is desired for a mix designed at four percent voids, the in-place density should be 96 percent of the reference laboratory density.

➤➤*Maximum Theoretical Density*

The maximum theoretical density provides the unit weight of the mixture as if it were compacted to a zero air void condition. Using the Rice test method (AASHTO T 209, ASTM D 2041), the maximum theoretical density of the field-produced mixture is determined as the reference density. The relative density of the in-place pavement is again calculated as the ratio of the in-place density to the reference density, which in this case is the maximum theoretical density:

$$\text{Percent of Maximum Theoretical Density} = \frac{\text{In-Place Density} \times 100}{\text{Maximum Theoretical Density}}$$

Since the maximum theoretical density represents a voidless mixture, an in-place air voids content of 8 percent will always be 92 percent of the reference maximum theoretical density, regardless of the mix design air voids value.

To obtain meaningful results, the field produced mixture samples must be cured to the same extent as was done during the mix design process. If the loose mixture samples are not adequately cured in the field, the target maximum theoretical density will be artificially low due to the relatively low asphalt absorption (resulting in greater mixture volume) which has occurred. Under this scenario, the in-place pavement density (and its inverse, pavement air voids) could be determined to be acceptable when in fact, the actual voids were substantially higher. This situation could lead to premature pavement deterioration, and it therefore illustrates the importance of proper curing of the field samples.

➤➤Control Strip Density

This process calls for the construction of a pavement control strip, also called a test strip, of a minimum length or tonnage of mix at the start of each pavement course being laid. The control strip is part of the paving project. A new control strip should also be constructed if major changes in mixture production or placement occur. A nuclear density gauge is typically used to monitor the densification process. A nuclear reading is taken at one or more locations on the mat after successive passes with each roller. When the maximum density of the control strip is achieved, the compaction process is complete. Maximum density is said to have been achieved when the increase in density after successive roller passes is less than 16 kg/m^3 (1 lbs/ft^3), or at some other value determined by the agency. After compaction of the control strip is completed, a specified number of bulk specific gravity (density) tests are measured on core samples taken from random locations within the control strip and averaged to obtain the reference density. The cores are also used to calibrate the nuclear gauge if further density control will rely on the nuclear readings. The reference control strip density must then be compared to either the laboratory or maximum theoretical density of the field-produced HMA to determine if densification is adequate and acceptable. Even though its maximum density was achieved during control strip construction, this density may not be at an acceptable level for good pavement performance. Several factors can affect the maximum density achieved during the placement of the control strip:

- Aggregate gradation
- Amount of crushed particles
- Asphalt binder content
- Mix temperature
- Weather conditions
- Number and types of rollers
- Material beneath the control strip

The combination of all the referenced factors must be controlled during the construction of a control strip. Manipulation of one or a combination of factors during production paving should not be allowed. It is also important that the material or pavement course beneath the control strip be essentially the same as the remainder of the area to be paved.

Once an acceptable control strip has been obtained, since the in-place density is exactly the reference density, typically 98 to 100 percent of the reference density is the desired average target density during construction. Also, individual test results should typically be no less than 95 to 96 percent of the target density.

➤➤Method Density Specification

A "method" specification, sometimes referred to as "ordinary compaction", has no reference density against which the in-place density and air voids are compared. This type of specification contains items such as number and type of rollers to be used, number of passes of each roller, use of temperature measurements, descriptions such as "surface is rolled until free of roller marks," etc. Judgment is the primary decision tool for determining optimum compaction when using this type of specification. Method specifications are generally only applicable for smaller projects with light traffic, areas inaccessible to standard compaction equipment, or thin lift construction (25 mm [1 in.] or less), such as leveling courses and thin HMA overlays. In these cases, cost and the inability to obtain meaningful data from thin, in-place pavements preclude the use of a reference density specification.

➤➤Reference Density Specifications

Satisfactory pavement performance resulting from the use of any reference density specification depends on such factors as:

- Properly designed and plant produced mixtures.
- Proper sampling and handling procedures of the loose samples from the mixing facility or roadway.
- Proper field laboratory testing procedures, especially correct compaction techniques and maximum theoretical density as appropriate.
- Proper sampling, handling, and testing of the pavement core samples.
- Adequate field confinement of the mixture during the compaction process.

The relationship between the reference density measurements and the air voids of the in-place pavement is shown in Figures 7.08, 7.09 and 7.10. An in-place air voids target equal to 8 percent is depicted against each type of reference density. Eight percent is selected here because it is believed that if this level of compaction is achieved at the time of construction, four percent air voids will be achieved in a few years after further densification of the pavement under traffic. Some agencies may prefer a target less than eight percent air voids in the compacted pavement. A target higher than eight percent is not recommended.

It should be noted that while the comparison between maximum theoretical density and in-place air voids content is a consistent one, the relationships between the other two reference density types and in-place air voids will shift up or down depending on the actual mix design and compaction criteria used in the specification. For example, if the mix design air voids is five percent as shown in figure 7.8, then 100 percent of laboratory density would be at five percent air voids. The required percent laboratory density to achieve 8 percent in-place air voids is 97 percent. If a compaction criterion of 96 percent of laboratory density were used, an in-place air void content of nine percent would result (not 8 percent).

Similarly, for a mix design air void content of 3 percent, as shown in figure 7.10, a compaction criterion of 95 percent of laboratory density is required to achieve in-place voids of eight percent. The compaction criterion mentioned in the previous example (96 percent) would result in seven percent in-place voids.

It is important to understand the relationships between the mix design air void content and its effect on reference density specifications. A particular density specification may provide satisfactory field compaction on one project, but due to changes in mixture design criteria, may be inadequate on another.

The use of reference density specifications (laboratory compaction, maximum theoretical and control strip) is appropriate for all projects with a lift thickness greater than 25 mm (1 in.). Each of the reference density specification procedures have additional considerations that may make one more favorable than another on a particular project. These considerations include traffic volume, subgrade support, size of the project, construction and testing schedules, and any lift thickness variation.

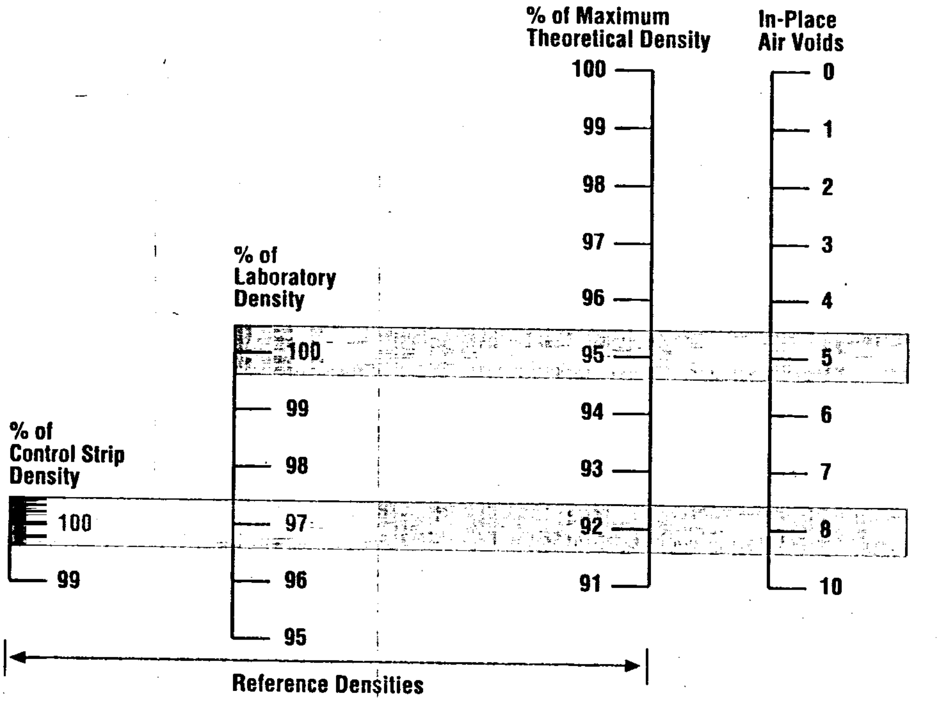

Figure 7.08 Relationship Between Reference Density and Air Voids for 5% Air Void Mix Design

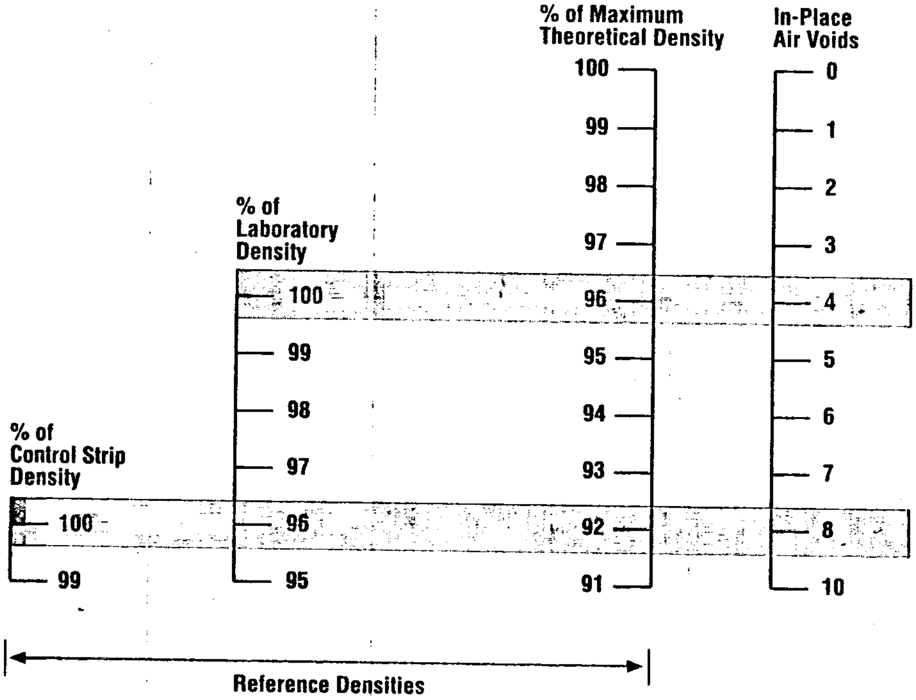

Figure 7.09 Relationship Between Reference Density and Air Voids for 4% Air Void Mix Design

Y C

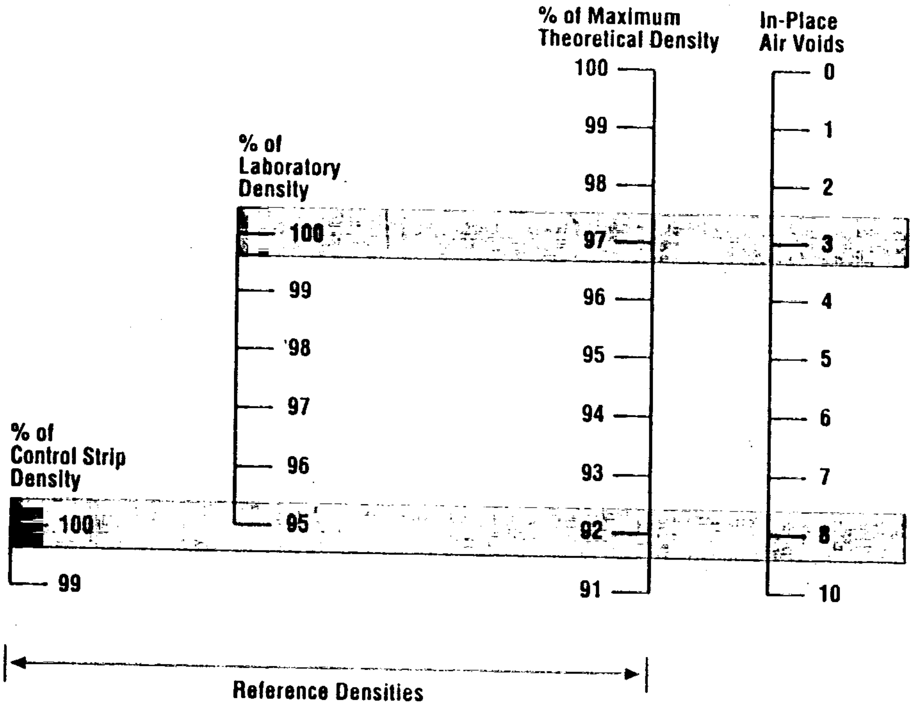

Figure 7.10 Relationship Between Reference Density and Air Voids for 3% Air Void Mix Design

When a specific reference density procedure (laboratory, maximum theoretical, or control strip) is chosen for a project, this same reference density process should be used throughout the testing and determination of in-place density. This will ensure that a valid comparison exists in the determination of density compliance. A higher degree of compaction monitoring is necessary in the initial stages of the construction process, regardless of the density specification used, to ensure optimum results from the compaction process.

In addition to minimum compaction, it is also necessary to avoid too much compaction. If high density (below 3 percent air voids) in a compacted mix is noted, the cause should be determined and corrected. This problem may also require that the mix be adjusted or redesigned. Pavements with an initial air void content below three percent are susceptible to permanent deformation and flushing after further consolidation due to traffic. Conversely, high initial air void levels, above eight percent, are likely to yield pavements which age prematurely. These low density pavements are more permeable to the damaging effects of air and water migrating into the interior of the mat. The result is a brittle pavement which is more likely to crack due to age hardening of the asphalt binder and effects of thermal expansion and contraction. These pavements are also more susceptible to stripping of the asphalt film from the surface of the aggregate, resulting in a reduction in pavement strength.

For these reasons it is recommended that compaction specifications require the resulting in-place air voids, immediately after construction, be between four and eight percent (96 to 92 percent of maximum theoretical density). Studies have shown this range in pavement air voids offers adequate resistance to air and water intrusion while allowing consolidation under traffic to take place without severe permanent deformation or flushing.

Summary

Based on the present knowledge of plant production and pavement behavior, quality control must be utilized to manage the process of asphalt mixture production in order to minimize the variability between mix design goals set in the laboratory and actual mix results achieved in the plant.

A statistically based sampling and testing program for quality control does not eliminate the need for adequate agency field inspection. Obviously defective materials should be considered for rejection, even though they may not necessarily be chosen for testing under the quality assurance process. For example, suppose a sublot is defined as containing 1000 metric tons (1100 tons) of HMA and the trucks delivering the mix to the project are averaging 20 metric tons (22 tons) per load. If the specifications require one sample of HMA be obtained for quality control testing per sublot, there is only a 2% chance that any single truck load would be chosen for testing. A properly trained field inspector would need to have the authority to recommend rejection of defective loads of HMA regardless of whether or not they are included in the test results. A defective load would have one or more obvious visual defects, such as contamination, excess asphalt, severe segregation or a temperature deficiency.

The in-place air voids of the HMA after compaction is probably the single most important factor in the acceptance procedure that affects performance of the mixture throughout the life of the pavement. However, specifying compaction is not sufficient for ensuring the success of a paving project or ensuring a durable, long lasting pavement. Compaction specifications are the final step in the total quality assurance of the HMA construction process. Proper mix design, production, quality control, construction and acceptance procedures must be integrated within the project requirements to achieve a quality product.

(1) D'Angelo, J. and T. Ferragut, "Summary of Simulation Studies From Demonstration Project No. 74 Field Management of Asphalt Mixes," Proceedings, Association of Asphalt Paving Technologists, Vol. 60 (1991) pp. 287-306.

(2) Bureau of Public Roads. V35, Report #9.

(3) Martinez, F. and Bayomy, F., "Selection of Maximum Theoretical Specific Gravity for Asphalt Mixture Design," Transportation Research Record 1300, 1991, p.17.