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OPTIMIZING USE OF MARSHALL ASPHALT MIX DESIGN

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ABSTRACT

Rutting has been a problem in Qatar's highway pavements since it began designing asphalt mixtures with the Marshall Method in the early 1990's. This paper describes specifications and rules-of-thumb which have been generated in the United States which may provide insight to Qatar's rutting problem and suggests modifications to mix design and construction procedures. The paper describes appropriate bitumen and aggregate specifications and discusses field procedures to implement mix design values produced in the laboratory. Maintaining 3-5% air voids in the mix is stressed at all times.

Keywords: Asphalt, Rutting, Compaction, Marshall design, Air voids.

INTRODUCTION

Qatar began designing asphalt pavement mixes with the Marshall design method in the early 1990's. The method has not proved entirely successful, with resulting pavement lives less than anticipated and rutting much greater than anticipated. The typical mixture consists of crushed local limestone with 60/70 pen grade bitumen; imported gabbro sometimes substitutes for part or all of the limestone aggregate [1].

The author has surveyed advisories, textbooks, and other technical memoranda used in the United States, which has more than 40 years of trial and error experience with the Marshall mix design method. The results of that survey are presented in this paper for comparison to current Qatar practice. They may suggest modifications to flexible pavement mix design and construction. Rutting is perhaps the chief mode of Qatar pavement failure. The National Asphalt Pavement Association (NAPA) states: "Resistance to permanent deformation is controlled by selecting quality aggregates with proper gradation and selecting the asphalt content so that adequate voids exist in the mix"[2]. Accordingly, discussion will be presented in five areas:

- Air voids following initial compaction
- Climate
- Aggregate materials
- Test procedures
- Field verification

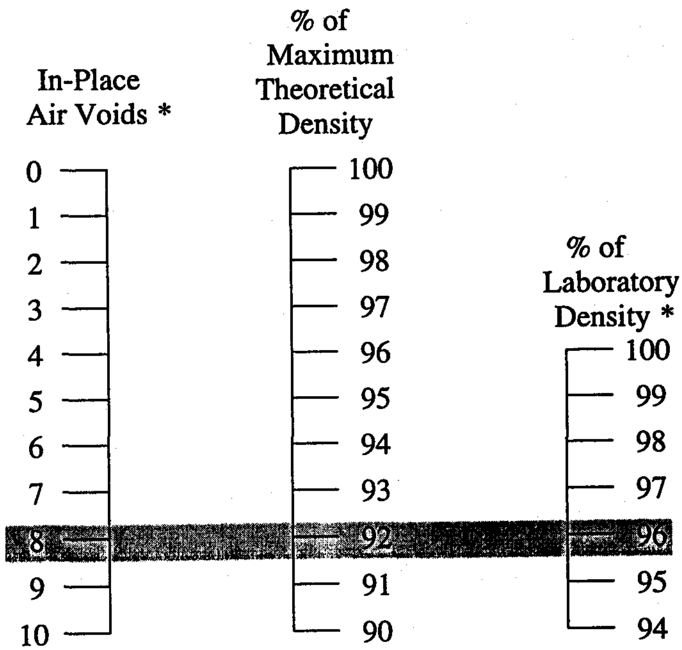
AIR VOIDS

Optimum air voids content for asphalt concrete at standard temperature is 4%, with 3% - 5% normally accepted. A higher percentage of air voids allows oxygen to penetrate the asphalt concrete, making it brittle. A lower air voids content promotes rutting on hot days, when bitumen expands and saturates the voids.

There is a popular misconception in the United States that compacted Marshall laboratory specimens represent the asphalt mat just after it has received initial compaction in the field. That is not the case; a compacted Marshall specimen represents the asphalt mat after traffic has further compacted the asphalt in the field for a period of two to three years [2]. Thus, if field personnel compact the asphalt mat to 100% of laboratory density, the mat will have air voids in the range of 3% to 5%.

Unfortunately, if the air voids are 3-5% after initial compaction, subsequent traffic will compact the asphalt even further, reducing the air voids to below the 3% value required to prevent saturation of the mixture on a hot day. Therefore, initial field compaction. should not be 100% of laboratory density; it should be 96-98% of laboratory compaction, allowing future traffic to bring the mat to the desired 3-5% air void range [3]. Figure 1 shows the desired reference density comparison.

If field personnel do not pay strict attention to compaction, they may over-compact the mix. The next few years of traffic will further densify the asphalt concrete. Then, on a hot day, the bitumen will expand, saturate the asphalt concrete, and cause instability (rutting).



* Assumes 4% air void content in laboratory specimen. Relative alignment of these two scales depends on actual mix design

Fig. 1. Reference density comparison

CLIMATE

The viscosity of asphalt cement (bitumen) decreases as temperature increases, so higher viscosity (lower penetration) bitumen is desirable in hot climates to prevent softening and therefore rutting. The Arabian Gulf and Qatar are home to an extremely hot climate. Unfortunately, the bitumen commonly available in the Gulf is a 60/70 pen, a moderate viscosity bitumen.

In the U.S., one of the most-used flexible pavement design methods bases its analysis on providing higher viscosity bitumen for higher temperature regions. The Asphalt Institute design method specifies three grades of bitumen for three typical U.S. climates as shown in Table 1 [4]. The average monthly temperature data for the three locations is given in Table 2 [5]. When Gulf temperatures are compared to the hottest United States temperature regime (Arizona) it is apparent that use of 40/50 pen asphalt may be helpful in Qatar to reduce rutting.

Table 1. Asphalt Grades for Different Temperature Regimes

Location	Mean Annual Air Temperature	Grades(Pen)
New York	<7°C	120/150, 85/100
South Carolina	7 - 24°C	85/100, 60/70
Arizona	<24°C	60/70, 40/50

A previous study did compare properties of asphalt mixtures made with 60/70 and 40/50 pen mixtures [1]. The two types of mixtures showed little difference when tested using Qatar National Building Specifications - Roadwork Section (QNBS) tests. However, as the author of the study correctly pointed out, those standards do not contain a test for rutting, and the author recommended field performance tests to gauge the effects of bitumen grade.

Bitumen Grading Method

It may even be appropriate for Qatar to consider changing from the penetration grading method to the viscosity grading method (AC 10, AC 20, AC 30, AC 40). Two reasons support such a change. The first is that the penetration grading system allows a broad range of viscosity within each gradation, as shown in Figure 2. For example, the 40/50 pen gradation covers the viscosity ranges of the AC-40, AC-30 (not shown), and AC-20 viscosity ranges. Thus, properties within a single pen grade can be highly variable and may not provide protection against rutting. A second reason is that the penetration test is performed at only 25°C, while the viscosity grading system performs tests at 60°C and 135°C. Tests at two temperatures allows the viscosity grading system some control of temperature susceptibility, an indicator of rutting potential. The penetration method does not measure temperature susceptibility because it tests at only one temperature. Additionally, the 25 °C test temperature for the penetration test is too low to measure the characteristics of bitumen at the high temperatures where rutting takes place.

TABLE 2. Mean Monthly Air Temperature for Three Representative Temperature Regimes

MATT	Mean Monthly Air Temperature - °C											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
7°C New York	-4	-4	-10	-3	6	9	19	21	18	13	9	5
15.5°C South Carolina	7	3	6	7	13	21	26	27	26	23	14	12
24°C Arizona	13	16	16	23	32	33	33	34	34	30	22	13

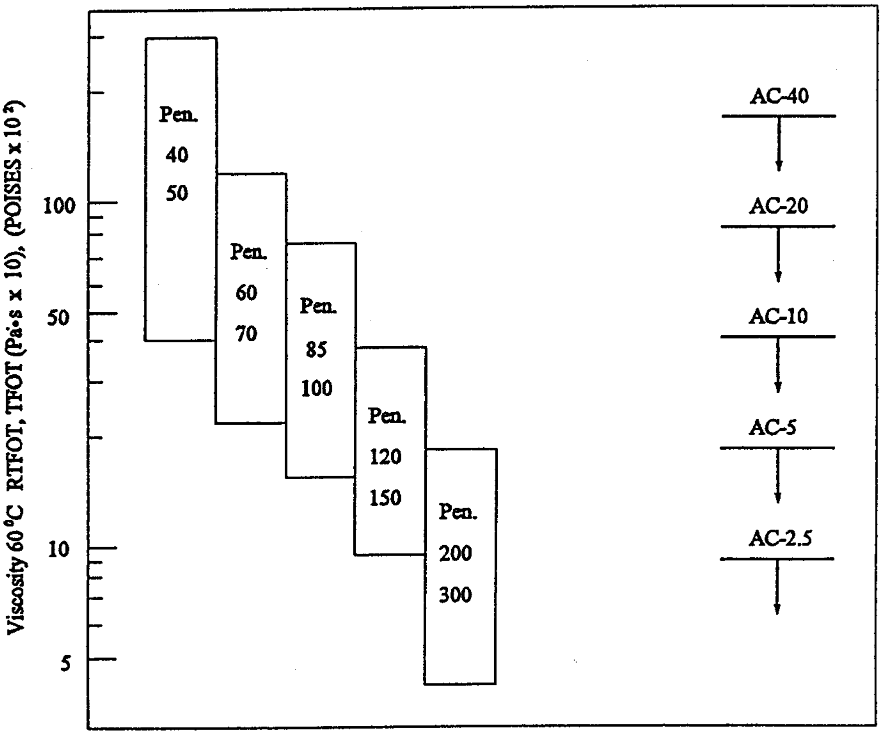


Fig. 2. Comparison of penetration grades and viscosity grades of asphalt cement (based on RTFOT residue for penetration grades; TFOT residue for AC-grades)

AGGREGATES

A United States Federal Highway Administration (FHWA) bulletin [6] comments on aggregate characteristics essential to asphalt mixture success. It discusses items such as durability, minimization of deleterious materials, abrasion resistance, etc. that are already covered by QNBS specifications. It provides several more specifications for limiting rutting:

- Because high aggregate surface friction contributes resistance to mix deformation, specifications should require at least 60% of the + 4.75 mm material to have at least two mechanically induced fractured faces.

- Because most natural sands are rounded and often contain a high percentage of undesirable materials, the amount of natural sand as a general rule should be limited to 15-20% for high volume pavements and 20-25% for medium and low-volume pavements.

- Asphalt mixes should specify a maximum fines-to-bitumen ratio ranging from 0.6 to 1.2 by weight. Higher values may encourage rutting.

The sand gradation within an asphalt mixture is critical to avoid rutting [2]. As illustrated in Figure 3, the aggregate gradation should not become horizontal and cross the 0.45 gradation line between the 0.3 mm and 0.6 mm sieve sizes. Gradations which exhibit that behavior are often tender mixes, which means that due to softness they may not compact successfully during initial lay down and may cause rutting problems later. Mixes which exhibit this type of behavior are often characterized by excessive use of natural sands.

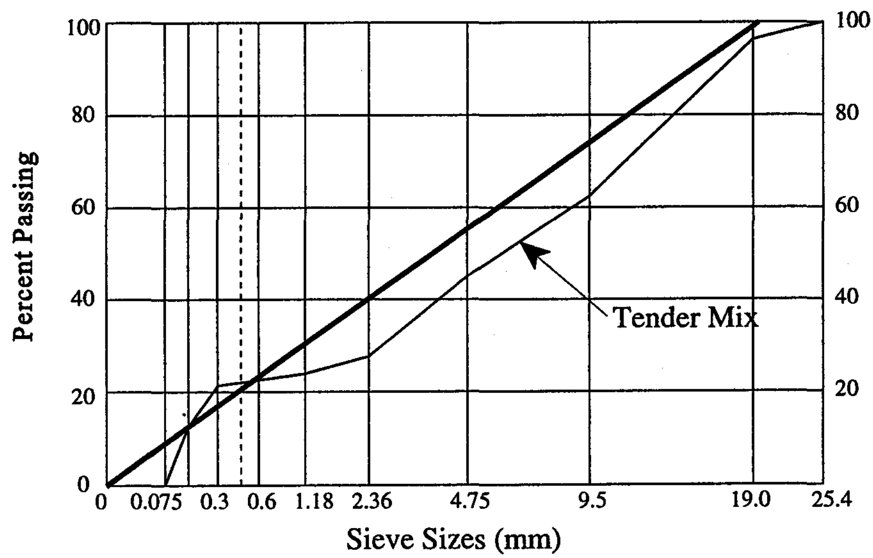


Fig. 3. Mix gradation on 0.45 power chart

In general, the mix gradation shown in Figure 3 would have been acceptable if the curve had run roughly straight from the value at 1.18 mm sieve size to the value at 0.075 mm sieve size. Please note that the "0.45 power chart" phrase in the figure title refers to graphing U.S. standard sieve sizes to the 0.45 power. Thus, the chart has been modified to include metric units for the sieve sizes. Also, the straight "0.45

gradation line" in the figure is drawn by connecting the origin with the percent passing the largest sieve size on which any material is retained.

LABORATORY TEST PROCEDURES

The Marshall laboratory test procedure is so complex that every aspect of it cannot be covered here. Discussion in this paper will be limited to two test aspects which may significantly affect percent air voids and asphalt content, which are key parameters involved with rutting.

The theoretical maximum specific gravity, Gmm, is measured using ASTM D2041. It is a key measure in both laboratory mix design and field verification procedures. Because it is used to calculate percent air voids, all parties agree that this aspect of the design method must be performed with utmost care.

A second aspect of the laboratory design procedures which can affect percent voids is the choice of compaction equipment. Compaction by hand often results in higher densities than those achieved with automatic laboratory compaction equipment because hand compaction brings the hammer into contact with the mixture at an angle, which produces a kneading action not produced by automatic equipment. Thus, the equipment used in the laboratory should match or produce similar results to the compaction equipment used to compact samples for field verification. If the equipment is different, proper comparisons between the job mix formula and the production mix cannot be made. Test results at the National Center for Asphalt Testing at Auburn University indicate that for heavy duty pavements, an automatic compaction device with a rotating base and slanted foot gives laboratory sample densities closest to field densities [2].

FIELD VERIFICATION

Field verification testing of the mixture is required because there are significant equipment and material differences between the mixture produced in the laboratory and the mixture produced on a large scale in the field. Field verification testing normally comes during two time periods: first-day testing and day-to-day testing.

First Day of Full Production Testing

Tests for asphalt content, aggregate gradation, maximum specific gravity, and bulk specific gravity are performed during the first day of full production testing. Air voids are calculated using the results from the maximum specific gravity and bulk specific gravity tests. It is essential that these tests be performed because field production of an asphalt mix subjects the aggregates to greater handling than it receives in the laboratory, and this greater handling may change the gradation by producing small particles chipped from aggregate. These small particles take up space that would normally be air voids. Frequently after first day testing, asphalt content in the mix formula may be reduced by 0.2-0.4% so that air voids can remain at the desired level. Thus, first day testing is important in the projects overall scheme for quality assurance and quality control.

Day-to-Day Testing

Day-to-day testing is performed to ensure that the field mix produced does not deviate from specifications. Typically, plots of such data as asphalt content, percent air voids, and aggregate percentages on various sieves are plotted on control charts four or more times daily. These charts provide warning that mix tolerances have been exceeded or may soon be exceeded.

Asphalt Institute Technical Bulletin No. 8 describes preliminary results of an FHWA demonstration project indicating the importance of field verification testing [7].

FHWA personnel visited fifteen states with a mobile laboratory and performed various test procedures on seventeen field-produced mixes. Along with job-mix formula verification tests, daily mixture verification was performed on an average of ten production days per mix.

The findings of this study demonstrate the necessity of field verification tests. Fifteen of the seventeen mixes did not meet the job-mix formula targets. Ten mixtures warranted adjustment before the desired mix properties were achieved. Five of the mixtures varied so significantly from the job-mix targets that redesign of the mix was deemed necessary. Furthermore, from the tests performed in daily mixture verification, the average percent air voids per study was 1.1 percent below the design target.

The mention of air voids 1.1% below the design target is particularly meaningful. It indicates that the bitumen may have insufficient void space to expand on hot days, resulting in rutting.

ALTERNATIVES

The activities described thus far have concerned modifying Marshall methods. Two other well-regarded methods of minimizing rutting which require more than Marshall modifications must be mentioned briefly. The first is the use of large top size (> 38 mm) mixes, which are generally acknowledged to provide greater strength and deformation resistance. Use of such mixes will require Marshall procedure modifications. For example, the mold diameter must be increased from 100 mm to 150 mm to accommodate the larger stones, and compaction effort must also be increased. In the field, modifications must also be made to prevent the mix segregation which is typically associated with large aggregate mixes. An example of a standard field modification is adding inserts to truck beds to minimize segregation while unloading dump trucks.

A second method is to add rubber modifier to the mix to provide higher viscosity at higher temperatures. Styrene-butadiene-styrene (SBS) is the most prominent example. It is added to the mix at a rate of 2%-6% by weight of bitumen. The result provides extra rut protection but is not without costs. The SBS often arrives in bags, so extra handling equipment may be required on site. Additionally, mix temperature requirements are usually 10° - 50° higher than for standard mixes, and the mixture is often considered "sloppier" and hard to work. Finally, the added cost of the modifier may be 8-12 Riyals/Mg of asphalt concrete.

SUMMARY

This paper has outlined problems and potential solutions dealing with laboratory and field asphalt mixes produced using the Marshall Mix Design Method. Most of the issues dealt with rutting because it has been the principal failure method of Qatar roads produced with Marshall mixes. The two principal reasons for rutting are low air void content and/or high bitumen content. In addition to discussions of aggregate gradation and sample compaction equipment, the paper has put forward the following recommendations to guard against those air void and bitumen content problems:

- Compact the asphalt mat in the field to 96-98% of laboratory Marshall density.
- Consider using 40/50 pen (AC-30, AC-40) bitumen, or consider adding laboratory testing which designs against rutting.

- Perform both initial and day-to-day verification testing to keep the field-compacted asphalt in the appropriate air void range. Initial testing may indicate that the laboratory-produced job mix formula must be altered by reducing bitumen content by 0.2-0.4%.

The recommendations have not yet been tested in Qutar and thus represent only an hypothesis. They provide a starting point and guide for future field studies.

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