Laboratory and Field Densities of Hot-Mix Asphaltic Concrete in Texas

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Laboratory and field data have been collected from twelve regular contract hot-mix asphaltic concrete paving projects in various areas of Texas for the purpose of comparing laboratory and field densities. Data from road samples taken from two to nine months after the roads were built show that five of the pavements exceeded laboratory density by 1 to 3 percent as determined by calculation methods currently used by the Texas Highway Department. None of the road samples measured by this method had a density lower than 97.2 percent (2.8 percent voids). The average density of the twelve different samples was 100.0 percent; the maximum density measured 103+ percent. The specific gravities of the mixes were then redetermined so as to include most of the absorption of asphalt cement by the aggregate. These data show an average of 94.6 percent, with a maximum of 97.3 percent. The range of differences brought out by the two methods was from 1.9 to 12.7 percent.

Data on mix design, traffic and field construction are included for background information.

●THE DATA PRESENTED in this paper are concerned with a portion of the research conducted for the Texas Highway Department by the Texas Transportation Institute on hot-mix asphaltic concrete. Studies are being made on the aggregates, the asphalt cements, the asphaltic concrete mixtures resulting from a combination of these materials, and the service behavior of the complete pavements in twelve different areas of Texas. Hot-mix asphaltic concrete designed to meet the current standard specifications falls into the general classification of dense-graded mixtures. As shown by data to follow, the specific mixes laid in different areas of the state show the considerable range in physical characteristics possible for such a material falling within a given set of specifications.

The particular point brought out in this part of the study deals with densification of the pavements by construction equipment and subsequent densification by vehicular traffic. Factors affecting pavement densification are considered and comparisons are drawn. The effectiveness of adequate and efficient compaction is shown and the need for more restrictive specifications is emphasized.

REVIEW OF THE LITERATURE

In 1937 Vokac (1), in a study of the service characteristics of 106 different cold mixtures with one year of service, made the following statement about voids in the finished mix:

> According to the data presented in this paper it is indicated that the one-year performance of a surface mixture is not critical to a reasonable precentage of voids. It is believed, however, that excessive voids would prove detrimental in a longer period of observation as excessive voids will undoubtedly permit the intrusion of moisture into the mix which may cause serious volume changes upon freezing. Moisture will also have a tendency to strip the bitumen from hydrophilic aggregates. The gradation of the aggregate is obviously an important factor in controlling the percentage of voids in the finished mix. Obviously, any expedient which will effect a reduction of the voids in a given aggregate will result in a greater strength with a given percentage of asphalt.

He also pointed out the importance of the compressive strength characteristic of a paving mixture and further stated that pavement resilience was not nearly as important as resistance to load. This was not qualified sufficiently and may be contradictory under certain circumstances.

Hveem (2), in 1940, observed that satisfactory aggregate grading curves tend to pass close to a point represented by the coordinates, 31 percent of the material passing a size equal to 0.031 of the particular maximum size of the gradation. Such curves are plotted on semi-log paper with the percentage retained on the arithmetic scale. Practical use of this observation is still made. For given materials and construction procedures, grading is an inseparable factor from pavement densification. All aggregate gradings studied in this project were checked against Hveem's "general grading chart." Reasonable compliance was found in all cases, although a number of the designers of these mixes were not aware of the existence of such a chart.

Kampf and Raisch (3), in their study of voids in paving mixtures, emphasize the importance of construction compaction and design of the mixture in the control of the voids of a finished asphaltic concrete pavement. In the compaction operation, the three items mentioned were weight of roller, temperature of mix during compaction, and stability of the mixture. The factors affecting voids in mix from the design point of view were listed as (a) the amount of asphalt cement, (b) the amount of filler (material passing the No. 200 sieve), and (c) available voids in matrix material.

In the research under consideration, the material passing the No. 200 sieve by wet sieve analysis was taken as filler in all instances.

Pauls and Rex (4) pointed out some of the problems associated with use of local aggregates. The questionable advantages of additives were discussed and it was mentioned that the aggregate, as well as the asphalt, is a factor in the selection of an effective additive. For one series of subangular aggregates tested, the use of 40-50 penetration asphalt was found advantageous from the stability viewpoint. For highly textured materials, penetration of the asphalt is a very minor factor in its effect on stability.

Hveem and Vallerga (5) stated that the terms density, permeability and compaction are related but not necessarily synonymous as they apply to bituminous mixtures. It was further stated that stability was neither related nor synonymous to the foregoing properties. That aggregate gradation has little predictable influence on stability was also mentioned. Experience with various aggregate gradings in Texas indicates that it is possible to produce stable mixtures although an aggregate grading may vary considerably between fixed maximum and minimum sizes.

Nevitt (6) mentioned the potential of the Texas gyratory shear compactor as an apparatus for laboratory compaction of hot-mix asphaltic concrete. This apparatus is simple and lends itself to field use quite readily. Correlation with field samples is shown later in data of this paper.

The data of Ortolani and Sandberg (7) compare favorably with the data presented, but indications are that present compaction equipment and procedures coupled with higher density and heavier traffic give higher field core densities than are obtained on laboratory specimens from the same mix design.

DESCRIPTIONS OF TEST SECTIONS

Table 1 gives the average daily traffic (ADT) for 1957 and 1958, the type of aggregate used in the various designs, and the type of base under each pavement. A study of the data to follow did not reveal any definite correlation between type of base and rate of densification, or type of base and density to date. The thickness of the layers placed, no doubt, is the prime factor for this lack of correlation.

It will be noted that the greatest thickness placed in any of the twelve roads was 2 in. The breakdown pass on all test roads was made with a 10-ton 3-wheel steel roller. In four instances a pneumatic roller was used for final construction densification. The effectiveness of this method is revealed by data to be presented. Actually, it is considered advisable by a number of asphalt paving technologists to use the pneumatic roller between the breakdown pass of the steel roller and the final rolling with a steel tandem roller. This procedure was observed in the construction of test sections 9 and

10. The rolling temperature given was the temperature of the mix immediately in front of the breakdown roller. No temperature measurements were made after rolling was completed.

Table 2 indicates considerable variation in the surface area of the aggregates used in the several test roads. The listed surface areas were calculated using the surface area factors suggested by the California Materials Manual (8). It is interesting to note that in the case of test section 4, with an asphalt content of 4.7 percent, there is an average film thickness of 4.81 microns, whereas test section 11 has a 4.4 percent

TABLE 1
TEST SECTION CHARACTERISTICS AND CONSTRUCTION DATA

Test Section	Traffic ADT 1957	1958	Aggregate Type	Base Type	Thickness of Surface, in.	Rolling Temp (F)	Roller Type
1c	4230	4600	Gravel and crushed limestone	PCC	1	310	10-ton, 3-wheel
1d	4230	4600	Gravel	Over 1c	3/4		10-ton, 2-wheel Light pneumatic
2	520	450	Gravel	PCC	1 3/8		
3	4220	4210	Crushed limestone	Flex.	2	310	10-ton, 3-wheel 15-ton, 2-wheel 20-ton, pneumatic
4	5410	5360	Gravel	PCC	1 3/8	300	10-ton, 3-wheel 8-ton, 2-wheel
5	1990	2280	Crushed limestone	Flex.	7/8 7/8	275	10-ton, 3-wheel 10-ton, 2-wheel
6	960	1060	Crushed limestone	Flex.	1 3/4	300	10-ton, 3-wheel 8-ton, 2-wheel
7	6040	6170	Shell	Flex.	1 1/2		10-ton, 3-wheel 10-ton, 2-wheel
8	6690	7090	Crushed limestone	Brick over PCC	1 1/4	250	10-ton, 3-wheel 10-ton, 2 wheel
9	20,000	21,660	Crushed basalt	2 in A C. over Flex	1/2	260	10-ton, 3-wheel pneumatic 260 lb/ in 8-ton, 2-wheel
10	15,000	5970	Gravel	Flex	1 1/2	310	10-ton, 3-wheel 8-ton, 2-wheel 25-ton pneumatic
11	17,500	18,200	Crushed limestone	PCC	1	300	10-ton, 3-wheel 8-ton, 2-wheel
12	5710	6430	Gravel	PCC	1 1/8	275	10-ton, 3-wheel 8-ton, 2-wheel

TABLE 2
AGGREGATE AND ASPHALT DATA

Test Section	Design Asphalt Content[1] (%)	Agg. Surf. Area (sq ft/lb)	Avg. Film Thickness (μ)
1c	6.2	36.36	8.75
1d	5.5	34.70	8.06
2	5.5	41.78	6.68
3	5.5	29.88	9.36
4	4.7	49.42	4.81
5	4.3	32.18	6.72
6	5.0	43.36	5.83
7	7.5	35.38	11.07
8	4.8	35.64	6.80
9	5.0	26.48	9.55
10	5.5	30.48	9.16
11	4.4	30.00	7.36
12	5.0	38.38	6.62

[1]By total weight.

asphalt content with a resulting average film thickness of 7.36 microns. The tendency in Texas is to go to thicker films in order to improve the flexibility characteristics and extend the useful life of the pavement. This, of course, can be done at no increase in amount of asphalt cement used by simply reducing the surface area of a mix design by aggregate gradation changes. Some consideration also is being given to use of lower penetration asphalt cement. The penetration grade now in general use in Texas is 85-100. The apparent advantages of a harder asphalt are attractive. The effective film thickness most suitable cannot be a singular one; this is evident from the host of variables already listed for the few test roads under study. The proper film thickness may vary 100 percent or more from one aggregate and service condition to another aggregate and service condition. Such factors as shape, surface texture and absorption of aggregate, weight and density of traffic, and climate, must be taken into account. As noted in Table 2, the variation in film thickness for the twelve roads under study is from about 5 to 11 microns. Careful evaluation of these pavements indicates that all but possibly one (test section 11) would give considerably better service over a longer period of time if the film thickness had been increased. Test section 2 is the most outstanding example of this need. Low traffic density points to the need for greater film thickness. Well rounded aggregates used in this design indicate the need of a harder asphalt, because stability as determined by the Hveem method is improved for such aggregates with lower penetration asphalts.

Table 3 emphasizes the variation in specific gravities obtained by different methods. The values in Col. a were obtained from laboratory compacted specimens by weighing in air and water, those in Col. b by formula consideration of the individual specific gravities of the various components making up a given mix design. If absorption is neglected—and it is for the values in Col. b—this would give the specific gravity of a voidless mix. In practice, however, absorption is a factor that must be considered if an accurate measure of final voids is to be obtained. In spite of the need for consideration of absorption, it is the practice in Texas with some exceptions, to disregard aggregate absorption.

Col. c gives the specific gravities of the mixes under study as obtained by measuring the weight and volume characteristics of the composite mixtures in the loose state. A

TABLE 3
SPECIFIC GRAVITY DATA

(a) Lab. Sp.Gr (gm/cc)	(b) Theoretical Sp Gr. THD (gm/cc)	(c) Imp. Sp.Gr. (gm/cc)	(d) Lab Theor. x 100	(e) Lab. Imp x 100	(f) Road Sample Sp. Gr. Mo. Value	Mo. Value	(g) Max.Rd. Lab. x 100
2.25	2.30	2.42	97.8	93	9mo	20mo	100.0[1]
					2.25	2.24	
2.31	2.38	2.42	97.2	95	8mo	20mo	101.2
					2.34	2 34	
2 22	2.35	2.42	94 5	91.8	5mo	19mo	94.2
					2.04	2.09	
2.28	2.35	2.41	97.0	94.6	8mo	20mo	99.2[1]
					2.26	2.26	
2.34	2.44	2.48	96.2	94.4	7mo	16mo	103 3
					2.42	2 40	
2.37	2.49	2.53	95 4	93.8	7mo	17mo	100.7
					2.33	2.39	
2.38	2.44	2.45	97.6	97.2	7mo	9mo	101 0
					2.31	2.40	
2.17	2.25	2.34	96 6	92.8	8mo	18mo	99.5
					2.12	2 16	
2.39	2.43	2.46	98 5	97.2	4mo	16mo	99.2
					2.34	2.37	
2.39	2.50	2.57	95.7	93.1	const.	19mo	101.2[1]
					2.25	2 42	
2.32	2.39	2.42	97.2	96.0	2mo	14mo	101.2[1]
					2.35	2.35	
2.43 THD	2.47	2 49	98.4	97.6	2mo	16mo	100.8
					2.42	2.45	
2.29	2.43	2.44	94 3	94.0	7mo	10mo	102.7
					2.35	2.31	

[1] Pneumatic
[2] Composed of two courses: laboratory data are on lower course, road data on combined courses.

wetting agent and vacuum are used in getting the displaced volume of the samples after the vacuum-saturation procedure of Rice (9) and Benson and Subbaraju (10). Although this method, which is used extensively in the materials research laboratory of the Texas Transportation Institute, is not assumed to give the final answer on degree of absorption, it does give an answer that is more realistic than that used in Texas as well as in several other states. The discussions to follow point out the reason for this statement.

Texas specifications (11) require density as measured on laboratory compacted specimens to be in the range of 94 to 98 percent, with 96 percent as the "optimum". Values of these measurements are shown in Col.d, Table 3. These values do not take into account any absorption of asphalt by the aggregate. Only samples 8 and 11 fall outside this range. On the other hand, these values shown in Col.e do consider the major portion of the absorption that takes place. Voids content as high as 8 percent is revealed, with a low value of 2.4 percent.

Up to this point the discussion has been concerned with laboratory measurements on mixes that duplicate the job formula. Because the practical aspects of the problem are concerned with what happens in the field, data from field specimens are necessary.

Road samples were taken from the test section at ages as shown in Col. f. Densities as obtained by a ratio of maximum road specific gravity over laboratory specific gravity (expressed as a percent) are shown in Col. g. The average of the 13 values shown is 100+ percent. This average has no practical meaning, but the value is mentioned for comparison purposes with the data of Philippi (12), who stated that field measurements indicated that field densities in Texas had approached laboratory densities on the average to within 0.8 percent. It was further stated that not within the life history of any bituminous concrete pavements had the field density exceeded the laboratory density. The data presented here indicate that more recent construction equipment and compaction methods make it possible not only to reach but also to exceed (with the aid of traffic) the laboratory density as indicated in Col. g.

Examination of the data indicates that the values in Col. e actually represent a more nearly correct picture of the percentage of solids in the laboratory specimens, inasmuch as these values have as their basis a voidless mixture (practically speaking). The values of Col. g should therefore be corrected to the same basis as that used in Col. e. This correction would result in a series of values ranging from 86.5 to 98.5 percent. This is another way of saying that the voids in the completed pavements may be said to vary from 1.5 to 13.5 percent rather than 1.5 to 5.7 percent as shown by the data of Col. d.

Which method is correct? In reality, neither is. Repeated tests with a variety of aggregates and mix designs by numerous laboratories in Texas have shown that it appears possible to have mixtures with well over 100 percent solids where mixes of increasing asphalt content are analyzed using the equation values of Col. d. This is possible only because absorption of the asphalt by the aggregates is neglected. If, however, these same mixes are analyzed by use of the equation of Col. e, none of the mixtures will show as much as 100 percent solids. It has not been found possible in this laboratory to prepare a voidless specimen by any known means of compaction, even though the asphalt content is allowed to vary from a low value (very dry mix) to a very high value (more than enough asphalt to overfill the total voids in the mineral aggregate).

The real picture of field density and laboratory density is revealed when these values are compared when both are calculated using the specific gravity as obtained by the vacuum-saturation method as the common basis. Such calculations show that eight of the twelve test sections have higher densities than the corresponding laboratory samples.

CONCLUSIONS

Realizing that these data are limited and incomplete in the sense that traffic will cause some further densification in some of these pavements, the following conclusions are presented:

1. Absorption of asphalt by the aggregate should be taken into account in all labora-

tory and field evaluations of bituminous concrete. The methods currently used by the Texas Highway Department for density evaluations do not account for asphalt absorption by the aggregate. This leads to fictitious values of percent solids—values as high as 103 or 104 percent.

2. The vacuum-saturation procedure of determining the specific gravity of the composite loose asphaltic concrete mix is reliable and gives practical specific gravity values that consider most of the absorption of the asphalt by the aggregate.

3. Texas Highway Department standard procedure for forming laboratory specimens of job formula mixes does not, as a general rule, produce ultimate density of the mix, because field samples of companion mixes from pavements less than two years old consistently show somewhat higher densities. This apparent contradiction of previous findings is explained by changes in construction equipment and increased weight and density of traffic.

4. The use of self-propelled pneumatic rollers between the breakdown pass and final rolling with a tandem roller is strongly recommended. In effect this hastens surface sealing and little change in density occurs in pavements so compacted.

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