Construction of Rut-Resistant Asphalt Mixtures

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In the last decade, operating tire inflation pressures have risen from 250 to 310 psi for fighter aircraft. Because these higher pressures bear directly on the pavement surface, the Air Force has begun to question whether asphalt mixtures are appropriate for fighter aircraft taxiways. Accelerated full-scale traffic of simulated F-15C/D fighters on flexible and composite test sections was studied. Half of the asphalt mixtures used for the test sections were designed with Marshall procedures and the balance with gyratory. The differences between the plastic behavior of the Marshall mixture and the stable performance of the gyratory mix were dramatic. The premature rutting of the Marshall mixture was caused by excessive asphalt for the applied traffic, which was caused by insufficient laboratory compaction during design of the mix. It was verified that the design process can ensure resistance to rutting of asphalt mixtures by simulating the compaction of aircraft in the laboratory with the gyratory testing machine. Heavier compaction equipment will be required when the leaner mixtures needed for modern fighters are placed on airfields. On the other hand, gyratory mixtures designed for lower contact pressures will be much more easily compacted, since they will have more asphalt. The granular layers contributed about two-thirds of the total surface rutting in all the flexible test sections, Marshall and gyratory.

For a decade, the deteriorating condition of America's infrastructure has been depicted as a national problem in the news media. Increasingly, concern relates to erosion of highway safety and operating economy due to surface rutting under truck traffic. Operating tire inflaction pressures have risen from 80 to 120 psi for trucks during this period. Rutting of military airfield surfaces has been a problem for half a century. Although relatively light, fighter aircraft usually carry 90 percent of their total weight on a pair of single wheels. As the weights of these aircraft increase, the tires are being inflated to increasingly higher pressures. In the last decade, operating tire inflation pressures have risen from 250 to 310 psi for fighter aircraft. Because these higher pressures bear directly on the pavement surface, the Air Force has begun to question whether asphalt mixtures are appropriate for fighter aircraft taxiways.

OBJECTIVE

The Air Force Civil Engineering Support Agency (AFCESA) has recently completed accelerated trafficking of test sections to study rutting of asphalt pavements under high tire inflation pressures found on aircraft such as late-model F-15s and F-16s. Earlier laboratory work (*1*) had indicated that resistance to rutting under these aircraft could be achieved in the mix design process. This research sought to validate the earlier work by determining whether mix design laboratories can achieve the densities produced by these aircraft, the resulting leaner mixtures can be compacted in the field, and the compacted mixtures can resist rutting under aircraft.

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TEST SECTION DESCRIPTION

To meet the objectives of this research, the AFCESA prepared flexible and composite pavement test sections (Figure 1) for accelerated aircraft traffic. The flexible sections were composed of 4- and 6-in. layers of asphalt concrete pavement over 12 in. of aggregate base and local dune sand subgrade. The composite sections were 6 in. of asphalt mixture over 12 in. of portland cement concrete. For the 6-in. sections, a 2-in. compacted lift was initially placed and compacted. This was followed by a tack coat and a final 4-in. compacted lift, which also paved the 4-in. sections. All characteristics of the surface course reported herein refer to the top 4-in. lift of asphalt concrete.

Characteristics of Granular Layers

The base course was constructed with 1 in. maximum northern Alabama limestone and compacted with a vibrating steel wheel roller to 100 percent modified Proctor (ASTM D1557) density of 141 pcf as measured by nuclear density gauges. Mean base course density was 141.5 pcf, with standard deviation of 2.1 pcf for 46 locations taken on centerline of proposed traffic. Mean sand subgrade density was 100.9 pcf, with standard deviation of 4.3 pcf for 33 locations taken on centerline of proposed traffic. The 100 percent modified Proctor density for this clean unified classification "SP" sand was 97.5 pcf.

Three random plate bearing values taken from the surface of the untrafficked base course averaged 667 pci, correlating with over 100 CBR and showing considerable surface strength. CBRs in the sand layer, taken after completion of all trafficking, ranged from 18 to 34 percent. The latter was probably more representative of the confined condition.

Characteristics of Asphalt Mixture

Asphalt samples were taken from the plant tank during production. The asphalt used was an AC-20 with penetration of

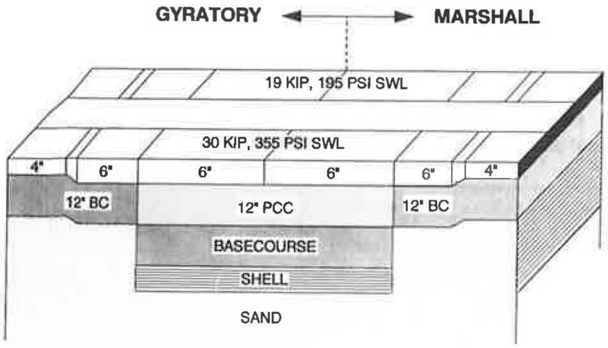

FIGURE 1 Section layout.

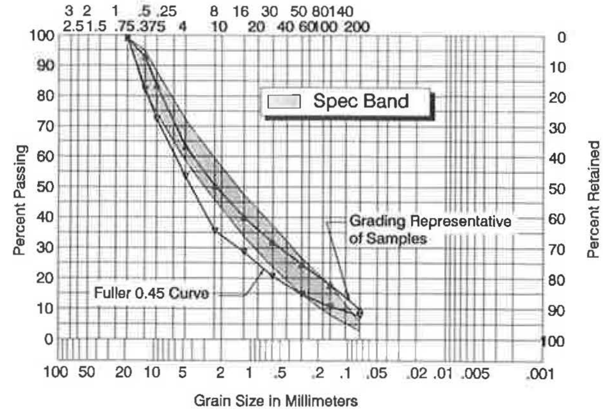

FIGURE 2 Representative grading for test section mixtures.

57, penetration index of −0.082, softening point of 128°F, kinematic viscosity of 471.8 cSt, and specific gravity of 1.0293.

The aggregate for the asphalt mixtures was 100 percent crushed, well-graded blends of ¾-in. maximum size Alabama limestone for the coarse aggregate and Florida limerock for the fine aggregate. The grading of stockpile samples conformed to that recommended for high-pressure applications in Air Force Manual AFM 88–6, Chapter 2, and is designated as the "spec band" in Figure 2.

A typical or representative grading of 17 Marshall and 10 gyratory samples from the paver, which is also shown in Figure 2, indicates a surplus in the minus #200 fraction, or dust smaller than 0.074 mm. Plant hot bin sample sieve analyses showed that most of it was produced while manufacturing the asphalt mixture in the 4-ton batch plant. This excess dust was reduced as much as possible by adjusting the hot bin proportions to get the representative grading shown. The Marshall and gyratory sections were placed with an average of 9.5 and 10.5 percent mineral dust, respectively. This is 50 percent more than the 6 percent maximum allowed in the DOD criteria.

Half of the asphalt mixtures used on the subject test sections were designed, following the procedures of ASTM D 3387, with the gyratory testing machine (GTM) developed by John McRae at the Corps of Engineers' Waterways Experiment Station. The gyratory design for these test sections was accomplished with compaction pressure of 300 psi, an angle of gyration of 1 degree, and a gyratory stability index (GSI) determined from stabilities after 30 and 60 revolutions. The widely used 75-blow Marshall method (Military Standard 620A, Method 100) was used to design the balance of test section mixtures.

Regardless of the design procedure used to select the binder content, both mixtures were subsequently checked against voids criteria commonly used with the Marshall procedure. Figures 3 through 7 describe the characteristics of the constructed mat in terms of these Marshall parameters for the top 4 in. of asphalt pavement. Whereas Marshall stability, air voids content, voids filled with asphalt, and, to a lesser extent, flow clearly differentiated between the Marshall and gyratory sections, voids in the mineral aggregate (VMA) were more similar. The gyratory sections received approximately 25 percent more rolling than did the Marshall sections; this was apparently sufficient to drive the gyratory VMA readings down to those of the better-lubricated Marshall mixture.

Characteristics of the Traffic

Traffic was applied while the temperature 3 in. deep in the asphalt ranged between 95°F and 130°F. The mean temperature at this depth during traffic was 104°F. These test sections

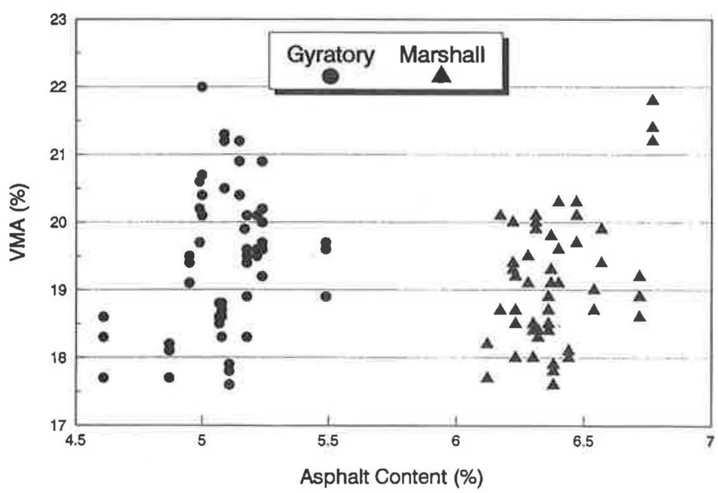

FIGURE 3 VMA of cores before traffic.

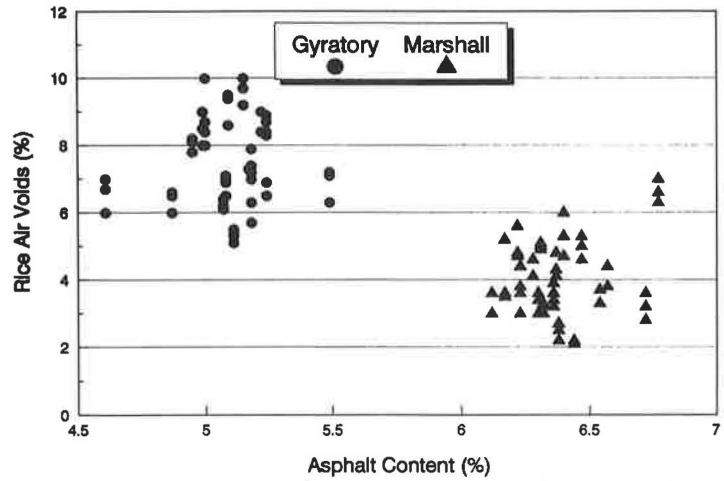

FIGURE 4 Voids of cores before traffic.

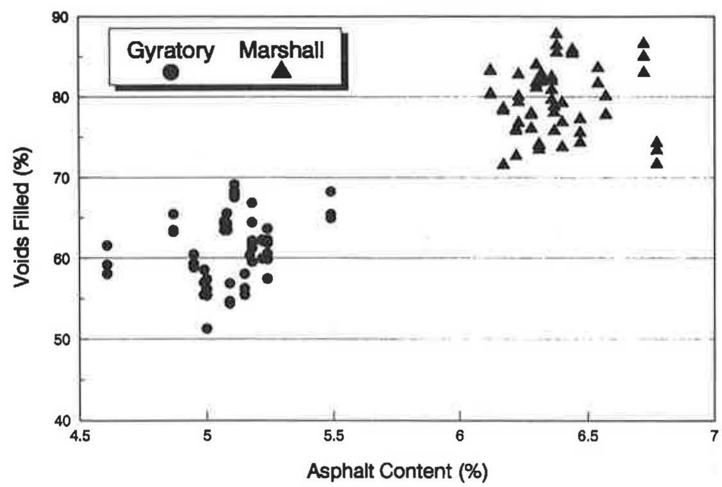

FIGURE 5 Voids filled of cores before traffic.

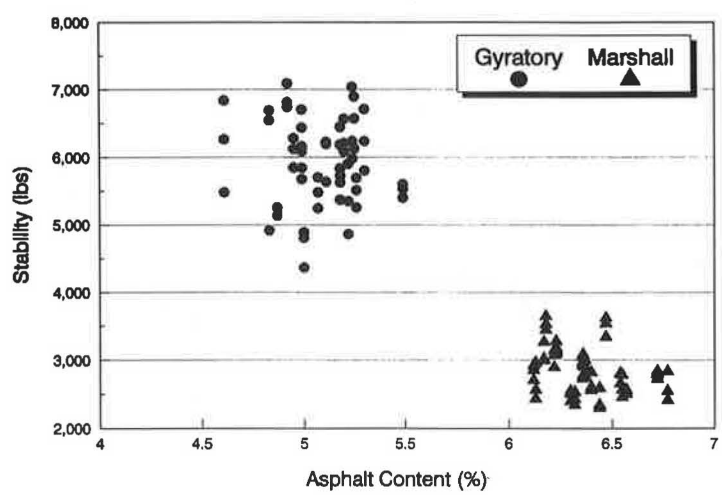

FIGURE 6 Stabilities of laboratory-compacted paver samples.

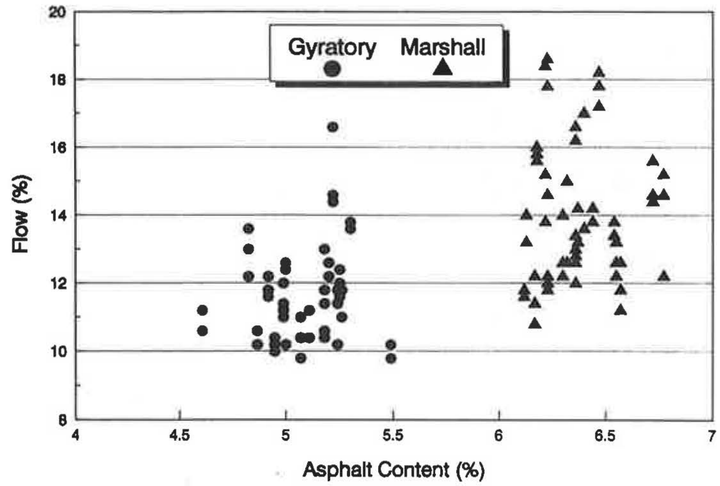

FIGURE 7 Flows of laboratory-compacted paver samples.

were trafficked with fighter aircraft wheel loadings of 29,600 and 19,000 lb having tire inflation pressures of 355 and 195 psi, respectively. The two loadings, which were intended to simulate fully loaded and unloaded F-15C/D fighter aircraft, were applied, back and forth, in a normal distribution across to the centerline. The number of actual applications of any portion of the load wheel over the centerline of the peak of the rut was typically 25 percent of the total traffic.

The speed, transverse and longitudinal location, and dynamic loading of the traffic were recorded for each pass of traffic. The aircraft and environment loadings that were measured in this test are characterized in considerable detail in other papers (*2,3*). The forward and reverse speeds of the fully loaded loadcart averaged 13 and 9 mph, respectively. Only the results of this fully loaded F-15 traffic are presented in this paper.

MATCHING LABORATORY COMPACTION TO THE TRAFFIC

Plastic behavior of the asphalt mixture under traffic can be predicted in the laboratory only if the compaction effort applied in the laboratory is equal to that of the expected traffic (*2*). Since traffic varies with function of air bases, the laboratory compactive effort must be adjustable to the traffic. The kneading compaction pressure of the GTM permits the attainment of proper densities at whatever compactive effort is desired. The 75-blow Marshall compaction currently used is a hammer impact procedure having a single compactive effort that cannot be increased without degrading the aggregate.

Figure 8 shows the excellent correlation obtained between final bulk densities produced by the F-15 traffic and gyratory compaction. The data point shown to have lowest density was from the end of the test section that was paved initially, after which the job mix formula was changed. Although it was not representative of the test sections as a whole, this data point was included to emphasize how well the GTM density simulated that of the F-15.

Figure 9 shows the use of two of the parameters in DOD mix designs, density and percent voids filled with asphalt (VF). The line designated as 85 percent voids filled refers to DOD limits for voids filled for absorbent aggregate. Densities of 20 Marshall and 15 gyratory core samples taken from the test sections after traffic are shown as data. When F-15 traffic was applied to the AFCESA test sections that were surfaced with the 6.4 percent binder mixture required by the Marshall design, the excessive compaction filled the mixture's air voids with asphalt. The load-carrying ability of the mix was transferred from the aggregate to the binder; plastic flow of the mixture ensued. Even the 5.1 percent asphalt mixture required by the gyratory design was trafficked into the upper boundary of criteria limits for VF. These show why the lab-

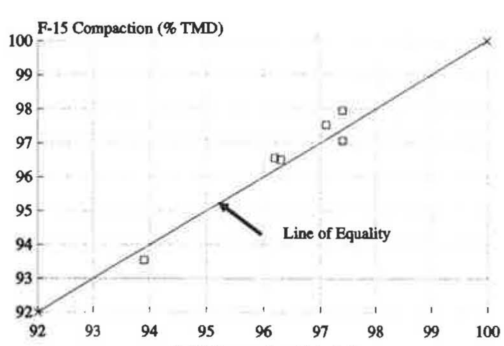

FIGURE 8 Laboratory versus traffic density.

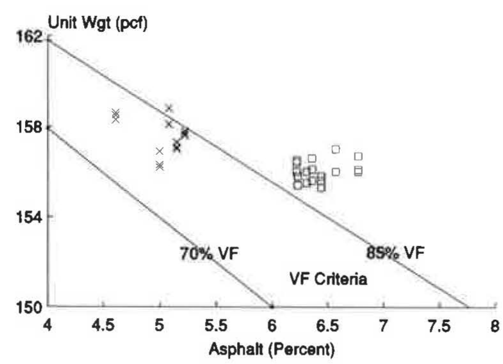

FIGURE 9 Final densities under traffic versus criteria.

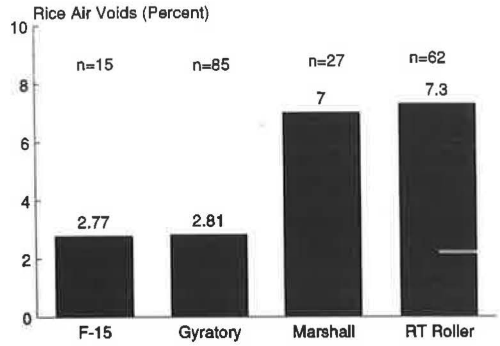

FIGURE 10 Effect of four levels of compaction on gyratory mix.

oratory density that is used to select the binder content of a mixture must match that of the traffic. For this particular aggregate, any asphalt content more than about 5 percent would be too rich and prevent the close packing of aggregate required to support the F-15.

Four levels of compaction of the gyratory mixture are shown in Figure 10, those of the two laboratory mix designs, the rubber-tire roller (RTR), and the traffic. On the average, 60 revolutions of the GTM produced laboratory densities equivalent to those from 10,350 passes of a loaded F-15. Marshall compactions of the same mixture averaged 93 percent theoretical maximum density (TMD), little more than the constructed mat density achieved by the RTR.

Production Effects on Marshall Mixture Compactness

Experience with Marshall compaction has been that asphalt mixtures will rut under traffic if the laboratory compaction produces a density higher than 97 percent TMD. Samples of this mix were taken from the paver and compacted by Marshall hammer into 78 specimens (Figure 11). Ninety percent of these compactions had less than 3 percent air voids. Since the mix design that was produced from stockpiles of the same aggregates provided from 3 to 5 percent voids, something in the manufacture of the mix (production of fines or more efficient mixing, or both) must have increased its susceptibility to compaction.

Because production changed the aggregate grading from that originally in the stockpiles, which had been used for both Marshall and gyratory mix designs, the mixtures placed as test sections were not optimum designs. Therefore, the Marshall mixture was redesigned by proportioning the material salvaged from the hot bins to produce a grading representative of the test section materials.

The new mix design, using the as-constructed grading, produced an optimum binder content of 5.8 percent. A glance at Figure 9 shows that this mixture would have been only a marginal improvement over the 6.4 percent binder, because F-15 traffic would have produced too much compaction to perform satisfactorily for any mixture of this aggregate with more than about 5 percent binder. These higher density mixes require a lower asphalt content. Otherwise, there will not be enough room for the asphalt when the air voids are reduced by traffic. The pore pressures that will develop under traffic will shove the aggregate apart. It is probable that the excess dust in this mix helped fill the air voids and to some degree increased the ease with which this mix could be compacted. However, the asphalt content of the Marshall mixture would have been too much for F-15 traffic, even without the added problem of excess dust. The Marshall compactive effort is too low to produce densities in the laboratory consistent with those produced in the field by the F-15 effect on the gyratory mix.

Production Effects on Gyratory Mixture Compactness

Samples of the gyratory mix were taken from the paver and compacted by GTM into 74 specimens (Figure 11). Sixty-seven percent of these compactions had less than 3 percent air voids; their average GSI was 1.057. Although these data indicated that the gyratory mix might rut, cores taken after 10,350 passes of traffic averaged 2.81 percent Rice voids, and there was little evidence of plastic flow. In fact, Figure 12 shows that densification of the gyratory mix was essentially

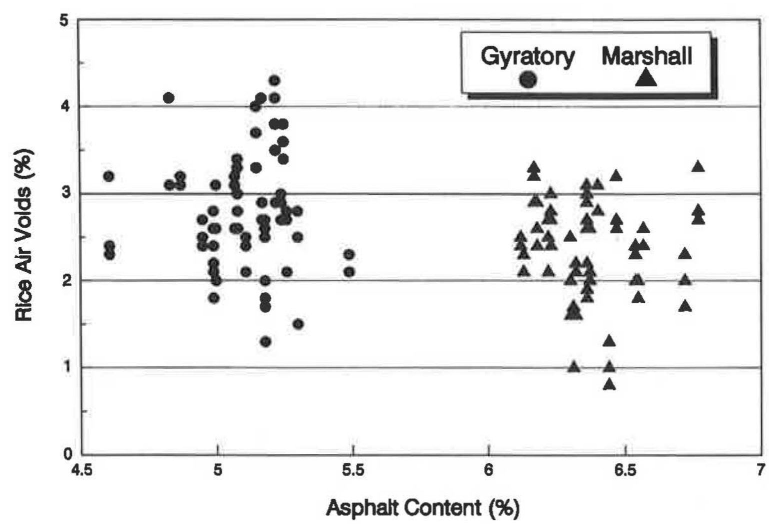

FIGURE 11 Voids of laboratory-compacted paver samples.

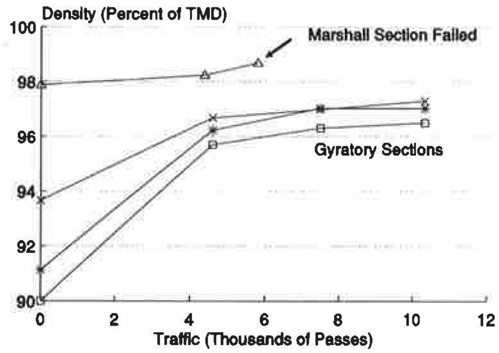

FIGURE 12 Densification under traffic.

leveling off after 10,000 passes, indicating that this mix might continue to carry the traffic. The performance of these sections challenges the premise that mix laboratory density cannot exceed 97 percent TMD.

FIELD COMPACTION OF THE MIX

The asphalt mixture was placed at temperatures between 260°F and 280°F and compacted between 250°F and 270°F. After breakdown with a static steel wheel roller, both the Marshall and the gyratory mixes were rolled with a conventional 6,000-lb-per-wheel, seven-wheel, sand-filled RTR until their densities peaked, as determined by nuclear meter measurements. Approximately 20 to 25 percent more rolling was required for the gyratory sections to reach peak density than for the Marshall sections. The latter were paved and rolled on the same day and with the same equipment as the gyratory sections. Densities of the joints were not monitored during this study.

Gyratory Sections

During and immediately following construction of the gyratory test sections, 15 samples that were taken from the paver were reheated and compacted in the laboratory; densities are plotted in Figure 13. Following compaction with the RTR, the densities of 56 cores were taken from the same locations as the paver samples and are also plotted in Figure 13. In this chart, the area defined as acceptable voids filled is labeled "VF Criteria." The DOD applies pay penalties for insufficient compaction when voids exceed 7 percent. Though marginal on the whole, it is obvious from Figure 13 that field compaction of the gyratory test section mixture was insufficient by current DOD standards. In fact, one-half of the initial mat cores from the gyratory mix had more than 7 percent voids.

On the average, the RTR achieved 1.03 pcf greater density of gyratory asphalt mixture over concrete than over granular base course. The difference was significant at 95 percent confidence levels for the gyratory mix, but not for the Marshall mix, where the difference was only 0.34 pcf.

Marshall Sections

The Marshall designed sections were constructed to an average of 96.0 percent TMD. For cores taken before traffic,

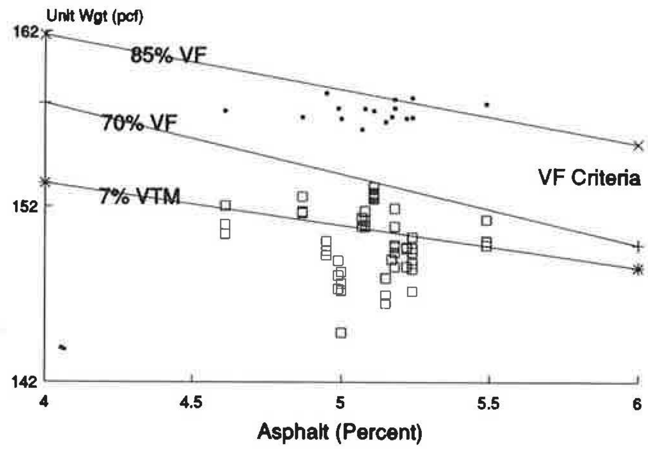

FIGURE 13 Laboratory versus initial field bulk densities of the gyratory mix.

the densities for 12 percent exceeded 97 percent TMD (Figure 3). The air voids in these locations within the Marshall sections were almost filled with asphalt at the start of traffic, and the mix probably began plastic deformation right away, leading to rapid failure.

RUTTING PERFORMANCE OF MIXTURES

Damage Parameters

The surface profile parameters used to quantify damage under traffic were obtained with a Rainhart profilometer. Only the true rut depth, which is the greatest measured displacement of the trafficked surface from its original elevation, will be discussed in this report. Readers interested in detailed measurements and variations of other rutting parameters are referred to the Air Force technical report (*3*).

Measurements of Surface Rutting

Figure 14 shows the entire range of rut measurements taken after 2,324 passes of the simulated F-15 for each of the six test sections. Since each plot comprises the true rut depths from 50 to 75 profiles at different locations on each test section, considerable variability is displayed.

The plots show most clearly that the flexible pavement surfaces rutted much more than did the composite surfaces. Such rutting in the flexible sections, even in the gyratory flexible sections, is classified as severe and unsuitable for normal military operations. The difference was much greater for Marshall than gyratory asphalt mixtures. All this implies that most of the rutting occurred in the granular layers and there was more granular layer rutting in the Marshall sections. The stiffer gyratory mix apparently protected its underlayment more than did the Marshall mixture. On the average, the granular layers contributed more than two-thirds of the surface rutting for both the Marshall and gyratory mixture flexible test sections.

The differential rutting between 4- and 6-in. surfaces is also clear from Figure 14. Traffic over the 4-in. Marshall test sec-

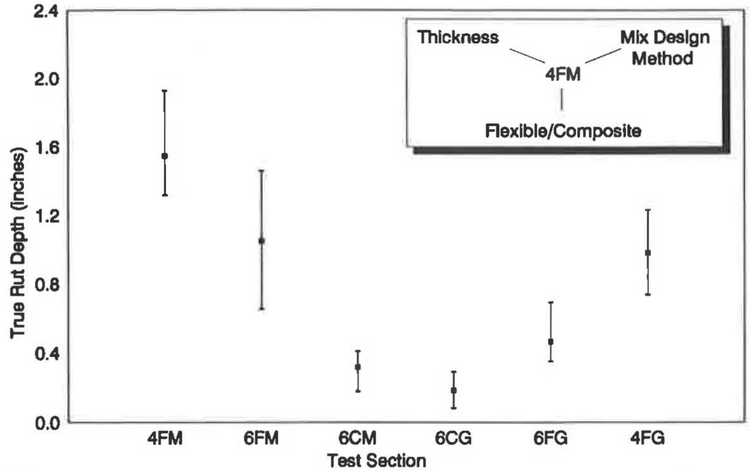

FIGURE 14 Means and ranges of surface rutting after 2,324 passes.

tion had to be stopped at this point; the load tire could not stand up to the rubbing of its sidewalls against the shoulders of the ruts in the plastic mixture.

Finally, the superior performance of the gyratory mixture can be seen by comparing the composite sections, where the base course rutting was not a factor. This is even more apparent in Figure 15, where the mean rut ± 2 standard deviations are displayed for a different number of profiles within each composite test section after 5,817 passes. These are the last available data from any of the Marshall sections; they show the dramatic differences between the plastic behavior of the Marshall and gyratory mixtures.

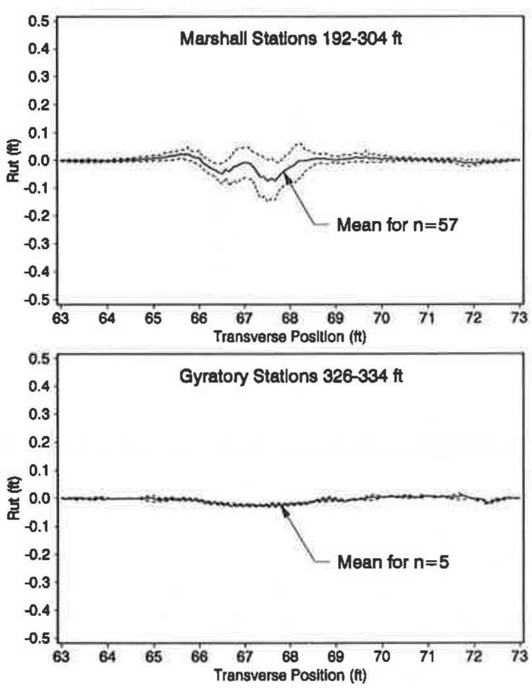

FIGURE 15 Surface rutting ± 2 SDs after 5,817 passes over composite sections.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory Simulation of Traffic Compaction

The premature rutting of the Marshall mixture was caused by excessive asphalt for the traffic applied due to insufficient laboratory compaction, exacerbated by dust produced when the fine fraction of aggregate degraded in the dryer. The gyratory designed mix remained stable to F-15 traffic throughout the test period and was not seriously affected by manufactured dust. In the design of asphalt mixtures for fighter traffic, the density from laboratory compaction must match that produced by field compaction. Only in this way can designers be confident that the correct amount of asphalt is chosen and that a mix so designed will not rut. Both the high pressures required by modern aircraft and flexibility to match their very different contact pressure levels exceed the limits of the Marshall method, but not that of the gyratory procedure.

Field Compaction of the Gyratory Mixture Was Insufficient

DOD and many state highway departments require mat density compaction of at least 93 and 92 percent TMD, respectively. These requirements ensure that newly compacted pavements are impermeable to resist oxidation of the asphalt and moisture damage. Target construction density should be about 94 percent TMD to ensure that these densities are achieved over the mat (*4*). Obviously, gyratory mixtures designed for lower contact pressures than those employed in the test would have had more asphalt and would have been much easier to compact.

In order to support modern fighters, however, mixtures will have to be leaner and more difficult to compact. Heavier compaction equipment will be required when mixtures such as the one used for these gyratory test sections are placed on an airfield. Comparison of Marshall and RTR data in Figure 10 shows dramatically how industry has developed construction equipment to achieve the Marshall compaction level and where it needs to be for the gyratory/fighter traffic level.

Asphalt Mixtures Can Be Designed To Resist Rutting

At this writing, work to explain large amounts of rutting in the base course and subgrade had just begun. Therefore, remedies will be proposed in later papers. As for the surface course, the gyratory mixture performed superbly and did not rut under the most severe loadings of the aviation industry. Conversely, rutting of test sections designed with Marshall compaction was plastic failure from the start. Only when agencies step out and specify gyratory design procedures will contractors adjust their compaction equipment to the levels required to compact gyratory designed mixtures. Such steps will be necessary if America's military and civilian infrastructures are to be maintained.

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