Field Compaction of Harsh Asphalt Mixtures for 2,067 kPa (300 psi) Tire Inflation Pressure

MYRON GELLER AND JIM MURFEE

The U.S. Air Force is concerned about the rapid and excessive rutting of asphalt pavements caused by the 2,067 to 2,756 kPa (300 to 400 psi) tire inflation pressures of modern fighter aircraft. Prior Defense Department research showed that these loads call for lower binder contents, and the appropriate binder amount can be determined by the Corps of Engineers' gyratory testing machine when operated at equivalent contact pressures. A taxiway was overlayed in late September at McEntire Air National Guard Base, South Carolina, by Rea Construction of West Columbia, South Carolina, to determine if harsh mixtures are constructible. The project required milling a 3.66-m (12-ft) wide keelway along the centerline of a 275-m (900-ft) by 15-m (50 ft) parallel taxiway and replacing it with 305 mm (12 in.) of drum mix, compacted in two 152-mm (6-in.) lifts. A nominal 102-mm (4-in.) overlay of the taxiway was placed in two sections, each 7.62 m (25 ft) wide by 275 m (900 ft) long. The allowable maximum compacted air voids was specified at 7 percent. The mean air voids of the compacted overlay, based on Rice theoretical density, was 6.8 percent, with some areas exceeding 7 percent. Periodic field inspections over the ensuing year showed no signs of surface material loss; nor was there any hint of rutting. This contract demonstrated that additional experience with harsh mixtures is all that is needed to construct asphalt mixes suitable for high tire inflation pressures.

F–15 and F–16 fighter aircraft generate average tire contact pressures in the range of 2,067 to 2,412 kPa (300 to 350 psi). These pressures accelerate rutting of asphalt concrete pavements at servicing airfields. The resulting plastic shear (rutting) is a grave concern of the U.S.Air Force (AF).

Investigations, under the auspices of the Air Force, were conducted to determine causes and possible solutions (*1*). The report concluded that the 75 blow Marshall procedure for determining the asphalt cement (AC) content of dense-graded hot mix asphalt (HMA) was inadequate, but that by using the Corps of Engineers' (COE) gyratory testing machine (GTM) to determine the AC content, HMA designs could be developed with the potential to withstand these higher tire contact pressures. These HMA designs would be lean mixtures for which the selection of aggregate type and grading would be critically important. For these mixes to be durable, they cannot be too porous.

In 1988, a field test evaluated such a design (*2*). The compaction of the harsh asphalt mixtures produced for this project was unsatisfactory. The Air Force subsequently sought to demonstrate the ability to compact these mixtures during the overlay of a portion of taxiway at McEntire Air National Guard (ANG) Base, where F–16 traffic was rutting the surface. Figure 1 shows that the base had relocated the centerline to avoid the ruts. Although the rutting was not typically plastic, it did appear to be relegated to the surface course. Previous removal of the surface for patching had revealed no deformation of the base course at any patch location. However, the base course was replaced with a bituminous keelway as part of this project. The ANG awarded the project in the early summer of 1993 to Rea Construction of Columbia, South Carolina. The project was completed in late September 1993.

M. Geller, 64 Mountain Avenue, Rockaway, N.J. 07866–1936. J. Murfee, 15139 Highway 77, Panama City, Fla. 32409.

OBJECTIVES

The project objectives were to (a) evaluate the ability to compact HMA mixtures designed with the COE gyratory testing machine while using current Department of Defense (DOD) recommended dense-graded aggregate blends designed for fighter aircraft and (b) use the COE GTM as a quality assurance tool.

PROJECT DETAILS

A 100-mm (4-in.) dense-graded HMA single lift overlay was constructed on a 275-m (900-ft) long, 15-m (50 ft) wide taxiway parallel to the main runway. Prior to constructing the overlay, a 3.7-m (12-ft) wide keelway on the centerline of the existing pavement was milled to the subgrade and filled with two 152-mm (6-in.) lifts of dense-graded HMA up to the original taxiway surface for a total compacted thickness of 305 mm (12 in.). The keelway provided a new base for that portion of the pavement width subjected to the traffic. This zone occurs on both sides of the centerline at an offset determined by the span between landing wheels, approximately 2.5 m (8 ft). The keelway required 640 Mg (706 tons) of HMA, and the overlay took 981 Mg (1,082 tons).

Actual Compacted Layer Thickness

The keelway lifts were both 152 mm (6 in.) thick after compaction. The overlay compacted thickness varied from 50 to 152 mm (2 to 6 in.) to provide a smoother centerline profile and 1.5 percent transverse slope runoff.

Mix Design

Aggregate

The coarse aggregate (sizes inclusive and larger than the No. 4 sieve) was 100 percent crushed. The stone was granite, quarried a

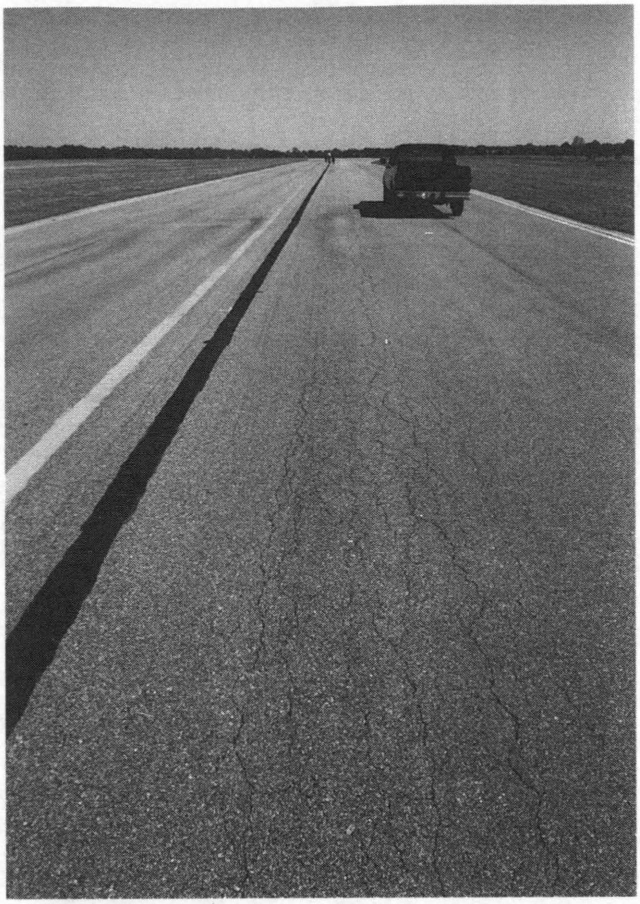

FIGURE 1 Rutting under F–16 traffic.

few miles south of the air base by Tarmac Quarry at their Palmetto site. The fine aggregate (smaller than the No. 4 sieve but retained by the No. 200 sieve) was crushed Palmetto granite screenings with no natural sand. Filler passing the No. 200 sieve was Palmetto stone dust, but it also included 1 percent lime. Table 1 shows the coarsest gradation allowed by AF specifications for contact pressures above 689 kPa (100 psi) and the job mix formula (JMF) gradation.

TABLE 1 JMF Gradation versus AF Specifications

Sieve Size	Wearing Course Percent Passing	Job Mix Formula
25.4 mm	100	99.5
19.05 mm	84 - 96	94
12.7 mm	74 - 88	78
9.52 mm	68 - 82	70
4.75 mm (#4)	53 - 67	60
2.36 mm (#8)	40 - 54	48
1.19 mm (# 16)	30 - 44	34
600 um (#30)	20 - 34	24
300 um (#50)	13 - 25	16
150 um (#100)	8 - 18	10.5
75 um (#200)	3 - 6	5.8

25.4 mm = 1 inch

Asphalt Cement

The asphalt cement conformed to ASTM D 3381 (Table 2), was grade AC–30, and supplied by Koch in Savannah, Georgia.

AC Content

The AC content for the job mix gradation was first determined at 5.3 percent by the 75 blow Marshall test procedure. GTM procedures, ASTM Test D 3387–83, indicated this mix would rut under fighter aircraft, unless the AC content was changed to 3.8 percent. Coarser gradations might also have resisted rutting but would have extended the scope of this project beyond current AF specifications. The modified AC content with the familiar gradation of Table 1 was targeted to produce the JMF.

Marshall Values

Table 2 compares the Marshall test values between the Marshall and GTM mixtures and describes the parameters used during the GTM procedure to modify the AC content.

GTM Settings

The compaction effort of the F–16 was simulated in the laboratory with 2,067 kPa (300 psi) vertical pressure and a 0.8 degree angle of inclination. The number of revolutions depended on when equilibrium density was reached. The temperature of the laboratory mix was 135°C (275°F) to simulate field temperatures during construction.

Quality Control and Assurance

One of every three trucks was sampled for temperature, gradation, AC content, and gyratory shear resistance. Each sample was taken from three different locations atop the truckload of mixture before it left the plant. Rice specific gravities were determined from six samples to establish a correlation curve between theoretical maximum density (TMD) and binder content; this curve was used to obtain Rice TMD for all samples. Field compaction was measured by a Troxler thin lift nuclear gauge model 4640 and confirmed by core samples the next day. The specification provided for two test strips; however, the two lifts of keelway mixture were used in lieu of test strips.

Compaction Specification

The minimum compaction required in DOD specifications without incurring pay penalties is about 93 percent of TMD. This was therefore the minimum acceptable compaction for this project.

Functionally, because lower regions of the pavement section experience less stress than do the surfaces, the vertical stress for the first lift of the keelway would be considerably less than that of the second lift and of the surface overlay. Consequently, the GTM ram pressure, which is the laboratory mimic of the field vertical stress, would normally be lowered from the 2,067 kPa (300 psi) surface

TABLE 2 Marshall JMF versus Gyratory JMF Values

Marshall Value	Marshall Design	Gyratory Design
AC Content (%)	5.3	3.8
Stability	11882 N (2670 lbs)	17342 N (3,897 lbs)
Max Flow	3.05 mm (0.12 in)	2.41 mm (.095 in)
Voids (%)	4	4.9
Voids Filled (%)	75.1	64.2
Voids in Aggregate Only (%)	16.1	13.7

course requirement to 827 kPa (120 psi) for the first lift. This lower laboratory compaction pressure would result in lower densities and more binder in the mix for the same percentage of TMD. However, because both keelway lifts also served as test sections for this project, it was necessary that they be compacted in the field with the same vigor as was the surface course. Therefore, for this project, the density and binder content requirements for the keelway were the same as those of the surface course.

Field Compaction

In addition to the contractor's 8- to 12-ton tandem roller, the Air Force provided compaction equipment for breakdown and intermediate rolling. The compaction equipment was operated under the direction of a compaction consultant, and it was stipulated that the laydown procedure be subordinated to the compaction procedure to maintain uniform temperature zones for compaction as the work progressed.

The preferred choice of rollers was a 13.6 Mg (15 ton) minimum static weight, vibratory tandem roller and a large pneumatic tire roller with sand or wet sand ballast, capable of generating 689 kPa (100 psi) ground contact pressure (GCP). However, because the large pneumatic was unavailable, a combination vibratory, pneumatic tire roller was used.

Breakdown Roller

One vibratory tandem was used with an operating weight of 16.8 Mg (18.5 tons). This roller had a 1.52-m (60 in.) drum diameter by 2.14-m (84-in.) drum width; each drum vibrated at 2,700 vpm. A choice of two centrifugal forces depended on selecting a nominal amplitude of either 0.41 mm (.016 in.) or 0.79 mm (.031 in.) with corresponding centrifugal forces of 9.5 Mg (10.5 tons) or 19 Mg (21 tons) per drum, respectively.

Intermediate Roller

One combination vibratory (combi) roller was used which had 4 large compactor tires, a maximum operating weight of 20 Mg (22 tons), and a vibrating drum with similar parameters as the vibratory tandem roller previously described, including comparable static drum module weight. This roller had four wide-base, compactor-tread, pneumatic tires, type 15.00 R 24 Pilote, each with a 3,100 kg (6,835 lb) fixed wheel load, 827 kPa (120 psi) maximum allowable tire inflation pressure; 406-mm (16-in.) wide tire base; and 533 mm (21 in.) center-to-center tire spacing. At 827 kPa (120 psi) tire inflation, each tire generated a 434 kPa (63 psi) GCP and a ground contact area (GCA) of 69,671 mm^2 (108 in^2). Unfortunately, knowledge of these relatively low roller load data were not available until the job was completed.

Finish Roller

The mat was finished with one 7.2 to 10.9 Mg (8 to 12 ton) static steel tandem roller that had a width of 1.37 m (54 in.).

CONSTRUCTION AND RESULTS

Production

A drum mix plant produced the mix; it was then stored in a silo and discharged to trucks on demand. Because the overall tonnage was low, the plant operated at less than its rated capacity. Because demand was controlled by compaction, the paver also operated at less than its rated capacity. This partly explains some of the variability in gradation and in AC content that was observed. The HMA was delivered at a temperature range of 143 to 149°C (290 to 300°F).

Keelway

Laydown

A single paver was used for the keelway laydown. Other than minor mechanical problems with the planer and the paver, the work proceeded in routine fashion. Each of the two lifts for the keelway was completed in about 3.5 hr of actual paving, with both lifts paved on September 23, 1993.

Raking

The longitudinal edge joints beneath the keelway and existing taxiway surface were not properly raked, and for the south joint, the paver screed overhang was excessive. These factors, in combination with excessive laydown thickness, required reworking portions of the joint. The rakers were instructed not to broadcast material behind the paver and were further instructed to rake the coarse particles out of the material making up the joint and to waste them. The raking problem continued into the first paving lane of the overlay, but disappeared during the paving of the second overlay paving lane.

Surface Texture and Segregation

The surface appearance of the mix had sections of coarse streaks and patches that indicated a lack of surface fines compared with larger areas of normal appearance. This appearance related to (a) the broadcasting of coarse material behind the screed, (b) other paver contributions to segregation, (c) the 25 mm (1 in.) effective maximum size gradation called for in the JMF, and (d) the tendency of the mix to segregate in the drum mix plant storage silo and paver. These coarse areas also appeared in the overlay (Figure 2).

Compaction Method

The mix behavior during breakdown and intermediate rolling was extremely stable, there was very little lateral movement and no roller bow wave effect. Checkmarks did not appear during two round-trip passes of the breakdown vibratory tandem, but they did appear after the first round-trip pass of the combi roller.

The keelway served as a confined test strip. The first lift was compacted on a clay subgrade having a California bearing ratio (CBR) of only 6. Both the vibratory tandem and the combi roller were operated at a slow walking pace of about 54 m/min (176 ft/min). Each roller made two round-trips per rolling width over each section. The vibrating tandem operated in the breakdown mode and the combi roller operated behind it in the intermediate mode, followed by the static 7.3 to 10.9 Mg (8 to 12 ton) tandem finish roller.

Two 2.14-m (84-in.) roller widths were required to cover the 3.7-m (12-ft) wide keelway, which resulted in a 0.6-m (2-ft) overlap down the center of the keelway. This width received double the compaction effort. It is significant that the mix was able to absorb this additional energy without signs of distress other than checkmarks.

All vibrating drums were operated at rated frequency and low amplitude. The compactor tires of the combi roller were inflated to 620 kPa (90 psi) tire pressure, with GCP of 372 kPa (54 psi) for the first lift and to 827 kPa (120 psi) with GCP of 434 kPa (63 psi) for the second lift.

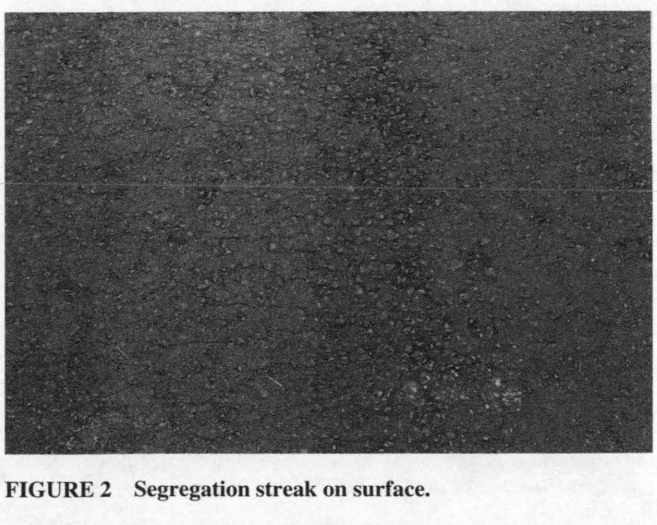

FIGURE 2 Segregation streak on surface.

Density Results

Nuclear Density A Troxler thin lift nuclear gauge model 4640 was used to measure the density results. From five sets of core densities taken the next day, the indication was that the gauge was reading about 48.1 kg/cu m (3 lbf/ft^3) lower than the core bulk densities for the first lift. The differential was more than 96.1 kg/cu m (6 lbf/ft^3) for the second lift of the keelway (Table 3).

Bulk Density Laboratory data containing bulk, Rice, GTM, and nuclear densities, as well as extraction results, are summarized in Table 3. (Specific data can be obtained in detail from the authors.) The five sets of core samples taken from the bottom lift before laydown of the top lift averaged about 8 kg/cu m (0.5 lbf/ft^3) less than did four bottom lift cores taken after construction of the top lift. Such results indicate the possibility that compaction of the top lift increased the density of the bottom lift. The top lift of the keelway had approximately 32 kg/cu m (2 lbf/ft^3) less density than did the bottom lift.

Asphalt Content Results

Five samples for AC content were taken from truckloads during bottom lift construction. The mean of the AC samples was 4.2 percent. Four samples taken from the top lift showed its binder content averaged 3.5 percent. These results indicate considerable difficulty controlling the binder content to 3.8 percent with both lifts of the keelway. The higher binder content of the bottom lift made attainment of that layer's density easier than that of the top lift.

Conclusions for Keelway

Largely because of excess binder, the first lift of keelway met the density criteria even though it was compacted on a weak subgrade. Conversely, the second lift of keelway was deficient in binder, and some areas did not meet the density requirements of the project. However, on the average, both lifts met density and were acceptable. Neither lift had the benefit of optimum equipment for the compactive effort required.

Overlay

Paving

The contractor elected to pave the 15.2-m (50-ft) wide taxiway in two 7.6-m (25-ft) lanes, using two pavers in echelon for each 7.6-m (25-ft) width. After the keelway was compacted, the paving lane was tacked, and a stringline was set along the centerline of the taxiway for the first 7.6-m (25-ft) lane. Upon the completion of one side of the taxiway, an approximately 152-mm (6-in.) wide strip was cut back along the taxiway centerline with a power saw, and the exposed edge was tacked before paving the second lane. The direction of paving was reversed for the second lane.

TABLE 3 Core Density/Percentage of Compaction Results

	Mean % AC	Bulk kg/cu m	Calc TM kg/cu m	Rice TM kg/cu m	GTM kg/cu m	% GTM	% Rice	Nuclear kg/cu m
		Mean Core Density/Percent Compaction						
Keelway Lift 1	4.2	2,352.7	2,480.7	2,480.5	2,344	100.5	94.9	2,296.9
Keelway Lift 2	3.5	2,318.1	2,505.8	2,487.9	2,385.1	97.2	93.2	2,216.5
Overlay	3.8	2,316.2	2,497.2	2,483.9	2,416.4	95.8	93.2	2,244.4

1 kg/ cu m = 0.06242 pcf

Note: The gyratory ram pressure was 827 kPa (120 psi) for the 1st lift of the keelway, resulting in a lower laboratory density, and 2067 kPa (300 psi) for the 2nd lift and overlay.

The work proceeded without any major complications. The 275-m (900-ft) long taxiway was divided into six equal sections of 46 m (150 ft). The pavers were restricted from proceeding from one section to the next until the breakdown roller was ready to begin rolling the section just completed by the paver.

During the laydown of the first 7.6-m (25-ft) paving lane, continued attention was given to screed and raking operations and to the frequency of clearing the paver receiving hopper. During the second 7.6-m (25-ft) paving lane construction, surface texture and joint construction improved substantially.

Compaction

Breakdown Roller Pattern The average rolling speed for breakdown was 54 m/min (176 ft/min) with both drums vibrating at low amplitude. Compaction of the 7.6-m (25-ft) paving width required two coverages. Each coverage received a total of four (round-trip) passes. Therefore two coverages required a total of eight round-trip passes (16 one-way passes), plus a deadhead pass to reach uncompacted material. Wasted motion for reversing and lane changes was estimated to increase the total rolling distance per section by 20 percent. For each 45.8-m (150-ft) section, it is estimated that the total travel distance of the roller was 20 times the section length. Passes away from the paver were slightly offset. The makeup pass was in the vibratory mode, specifically made in the rolling lane adjacent to the centerline of taxiway. It was intended to ensure greater compaction in the traffic zone of the taxiway.

Temperature Zone Breakdown rolling took place within a temperature zone of 127 to 149°C (260 to 300°F).

Intermediate Roller Pattern The average rolling speed for breakdown was 54 m/min (176 ft/min) with the vibrating drum leading into the paver at low amplitude. The pneumatic wheel loads were 3,100 kg (6,835 lb) each, 827 kPa (120 psi) inflation pressure, giving a GCP of 434 kPa (63 psi) and a GCA of 69,671 mm^2 (108 in.^{2}). Compaction of the 7.6-m (25-ft) paving width required two coverages. Each coverage received a total of four (round-trip) passes. Therefore two coverages required a total of 8 round-trip passes (16 one-way passes), plus a deadhead pass to reach uncompacted materials. This was the same as that of the breakdown roller because both were 2.14 m (84 in.) wide (Table 4).

Pilote Tire Table 5 provides the closest domestic equivalents for GCP and GCA at the same approximate wheel load and tire inflation pressures as the Pilote. It also provides equivalent tire inflation pressures and GCA values that have approximately the same GCP as the Pilote tire.

The two sizes of domestic equivalents to the Pilote tire generate substantially higher GCP and lower GCA values than the Pilote at about the same wheel load. To generate a higher Pilote GCP, the wheel load should increase from 3,100 kg (6,835 lb) to 4,540 kg (10,000 lb) or more. This requires an increase in machine weight of 7,895 kg (17,390 lb), which is obviously impractical. However, with a large GCA of 69,671 mm^2 (108 in.^{2}), a GCP of 434 kPa (63 psi) is still broadly effective, but upward adjustments of GCP are impractical.

For the spacing that was used between the breakdown and intermediate rollers, a higher GCP would have been more effective; alternatively the spacing could have been decreased.

Temperature Range Intermediate rolling operated within a temperature zone of 104 to 127°C (220 to 260°F).

Edge Marks This mix design was sensitive to steering edge marks. It was necessary to increase the reversing distance traveled by all of the rollers during lane changes to permit more gradual steering and to avoid making edge marks.

Quality Control Compaction quality control during construction keyed on each section as the intermediate roller compacted that

TABLE 4 Rolling Sequence of Passes

COVERAGE NUMBER	NUMBER DRUM WIDTHS FROM CENTERLINE 1	2	3	4
	PASS NUMBER			
1 IN	1	3	5	7
1 OUT	2	4	6	8
2 IN	15	13	11	9
2 OUT	16	14	12	10
MAKEUP PASS	17			

TABLE 5 Comparison of Pilote Tire with Domestic Equivalents

Tire Inflation kPa (psi)	Wheel Load kg (lbs)	GCP kPa (psi)	GCA mm^2 (in^2)	Tire Type
345 (50)	2724 (6000)	400 (58)	66445 (103)	11:00x20, 18 ply
482 (70)	2724 (6000)	482 (70)	55479 (86)	11:00x20, 18 ply
827 (120)	2724 (6000)	655 (95)	40641 (63)	11:00x20, 18 ply
413 (60)	2996 (6600)	517 (75)	57414 (89)	13:00x24, 26 ply
861 (125)	2996 (6600)	744 (108)	39351 (61)	13:00X24, 26 ply
827 (120)	3103 (6835)	434 (63)	69671 (108)	15.00 R24 Pilote

section. Unless extra care was taken to ensure that the nuclear gauge was placed on a perfectly flat surface (one unaffected by the tire imprint), faulty readings resulted. More reliable readings followed the finish roller. However, this impedes corrective action because the intermediate roller has moved to the next section by the time readings are taken after the finish roller.

Tire Pickup About 15 min before the first use of the combi roller, the tires were misted with diesel fuel by a grader-type sprayer. Neither water nor diesel fuel was applied to the tire during compaction, and no material pickup was observed. It was not necessary to repeat the misting application unless the tires were allowed to cool.

Finish Rolling Because the finish rolling width was 1.37 m (54 in.), it required more total rolling distance per coverage of the 7.62-m (25-ft) paving span. The finish rolling speed was increased to keep the roller in phase. As long as steering maneuvers were made in a gradual way, the roller did not influence the rate of compaction. The finish operator was given special instructions to look for drum edge cut marks in the pavement and remove these and other blemishes. The finish rolling was performed within a temperature range of 71 to 93°C (160 to 200°F). Nuclear gauge spot checks indicated that, at times, the finish roller was able to increase density slightly.

Core Density Results

Table 3 includes the compaction results from the overlay construction. On the average, compaction comparisons to Rice TMD were about the same as the second lift of the keelway (Figure 3). However, the gyratory results in Table 3 show that higher densities should have been achieved in the overlay. The influence of higher binder content in the overlay laboratory samples is very evident in the gyratory results but not in the field results. Of course, this could also mean that the laboratory samples used for gyratory analysis were not representative of the material from where the cores were taken. When calculated, instead of using Rice measurements, the mean overlay core void content was 7.2 percent, the VMA was 15.7 percent, and the VF was 53.9 percent.

Percentage of Binder

From 14 samples taken from the overlay material, the mean value of binder content was 3.8 percent with a standard deviation of 0.2.

Overlay Conclusions

The average compaction results of 93.2 percent TMD barely met the threshold requirement of 93 percent, indicating that several areas were insufficiently compacted (Figure 4). Two of the probable reasons for this were insufficient GCP with the combi roller and failure to use the intermediate roller as early as was possible. The intermediate roller pattern was not begun until the breakdown roller began deadhead pass No. 17. It was possible to begin intermediate rolling sooner. The advantage would have been a higher average mat temperature during intermediate compaction and a lower resistance of the mix to the compaction effort for which the GCP of 434 kPa (63 psi) could have been adequate.

Because of the experimental nature of this project, the quantity of mix produced each day was far less than optimum for the drum plant employed. There were problems controlling gradation and binder content. The average difference between nuclear and bulk densities doubled from one day to the next due to these variations in mix characteristics. Because this project was so short, this information was unavailable to the field in time to make changes in compaction efforts.

Segregation of the mix was apparent, as exhibited by patches of coarse material. Part of the problem was the relatively fine grading of the mix and the use of a 25-mm (1-in.) effective maximum size of aggregate. In addition, laydown construction procedures for joints and raking were not good initially; however, this improved during the course of construction.

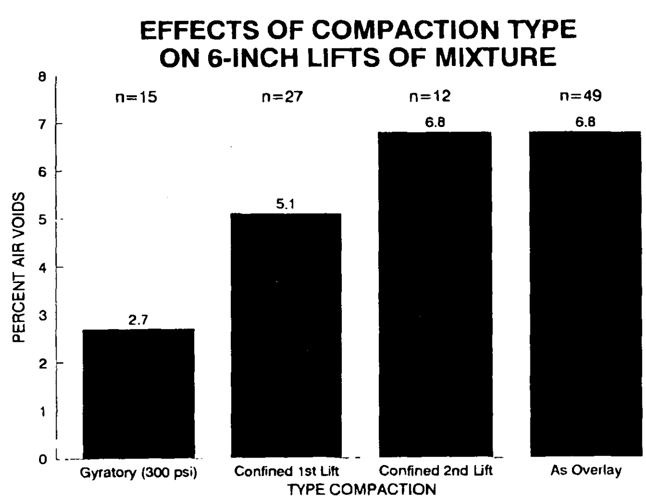

FIGURE 3 Compaction effects on 6-in. lift.

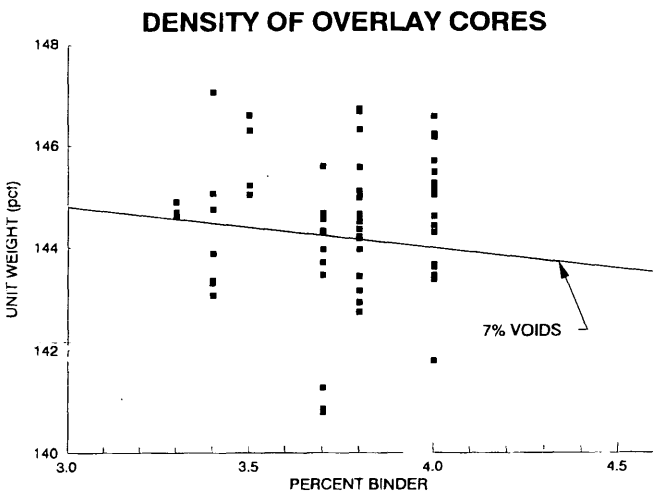

FIGURE 4 Overlay core densities; the bottom line.

GENERAL OBSERVATIONS

Thick Lifts [More than 75 mm (3 in.)]

HMA for which the binder content is determined by a GTM set for 2,067 kPa (300 psi) ram pressure and a 0.8 degree angle of gyration can be compacted to customary DOD air voids requirements of less than 7 percent. The following precautions are recommended:

- Suitable rollers must be selected. The minimum requirement for breakdown is a 9.07-Mg (10-ton) vibratory tandem roller. The minimum requirements for the intermediate roller are a heavy, large pneumatic tire roller, with wheels having a minimum 508-mm (20-in.) rim, ballastable to 2.72 Mg (6,000 lb) wheel load (3.63 Mg, or 8,000 lb, for 610 mm or 24-in. rim), and tires inflatable to 723 kPa (105 psi). The intermediate roller shall have a minimum GCP of 655 kPa (95 psi).
- For new mix designs, roller test strips should be used to establish a suitable rolling pattern. However, unless the nuclear gauges are correlated early on, as part of the test strip procedure, to the measure of density that is used for control, difficulties may arise. The sooner test cores are taken and test results are given to the test strip coordinator, the earlier adjustments can be made to the rolling pattern.
- If rollers of different widths are used, it is essential to adjust the roller speeds so that the rollers stay in phase.
- For rut-resistant HMA, rolling discipline is essential to ensure that compaction takes place within controlled temperature zones for the breakdown and intermediate rolling modes.
- Control zones are established to ensure synchronization among the paver, breakdown, and intermediate rollers. Breakdown and intermediate rolling should be close-coupled to prevent unnecessary cooling between compaction modes. The use of markers to delineate rolling sections is beneficial for compaction uniformity and also serves to keep the paver in phase with the rollers.
- The use of a tamping screed for the paver should be considered if the synchronized average paving speed does not exceed 4.6 m/min (15 ft/min).

Thinner Lifts

Compaction of thinner lifts of these types of mixtures should be possible. However, in several respects, paving and rolling disciplines will become more critical.

- As the layer thickness decreases, the inhibiting effect of the underlayer on particle movement will increase. As compared with thicker lifts, the number of roller passes may not decrease, and the travel speed of vibratory rollers may not increase.
- For a given laydown rate, paving speeds increase as the layer thickness decreases. This tendency must be subordinated to the requirement that the distance the paver travels per paver working hour be synchronized with the distance the roller train can advance per roller working hour.
- As layer thickness decreases, the cooling rate increases, thereby reducing the allowable time for rolling. Because lean HMA requires more compaction energy to satisfy a low residual air voids specification, this trend toward more compaction effort (i.e., more roller passes), conflicts with one that reduces the allowable rolling time.

GTM as a QA Tool

- During this project, the on-site GTM produced two to three shear strength evaluations during the interval required to sample every third truckload of mix. Although extraction data were unavailable for hours, the shear resistance of the mix was quantified in the GTM before the truck reached the job site.
- The equilibrium density attained in the GTM was an excellent laboratory parameter with which to evaluate compactibility, as was done with the core densities in Table 3.

Performance

As of this writing, the McEntire pavement has been in service 13 months. There has been no rutting, despite F–16 traffic (albeit light) having 2,274 kPa (330 psi) tire inflation pressures, and no evidence of loose aggregate, despite twice daily scourings with sweepers.

RECOMMENDATIONS

Previous work (*1,2*) has shown that rut-resistant asphalt mixtures can be designed using the COE GTM. This project has shown that pavements using these mixtures can be constructed, and that industry experience using them is needed for durable mixes.

The authors recommend that for all dense-graded airfield pavements, particularly those designed for fighter aircraft, the GTM be part of the mixture binder content selection process. This is particularly important for traffic having tire pressures greater than 1,378 kPa (200 psi) so as to prevent plastic shear of the mix under traffic.

ACKNOWLEDGMENTS

The research described in this report was funded by Wright Laboratory, Flight Dynamics Directorate, Vehicle Subsystems Division, Air Base Systems Branch, and the Air Force Civil Engineering Support Agency, Engineering Division, both at Tyndall Air Force Base, Florida. Construction was funded by the SCANG's McEntire Base Civil Engineer and performed by Rea Construction of West Columbia, South Carolina. Myron Geller supervised the compaction. Inspection and quality assurance was provided by Applied Research Associates, Gulf Coast Division; the COE Waterways Experiment Station of Vicksburg, MS; SCANG; and the Engineering Development Company of Vicksburg, Vicksburg, Mississippi.

REFERENCES

1. Regan, G. L. A Laboratory Study of Asphalt Concrete Mix Designs for High Contact Pressure Aircraft Traffic. AFESC Publication ESL–TR–85–66. Tyndall AFB, Fla., July 1987.
2. Murfee, J. and C. W. Manzione. Construction of Rut Resistant Asphalt Mixtures. In *Transportation Research Record No. 1337,* TRB, National Research Council, Washington, D.C., 1992.

Publication of this paper sponsored by Committee on Flexible Pavement Construction and Rehabilitation.