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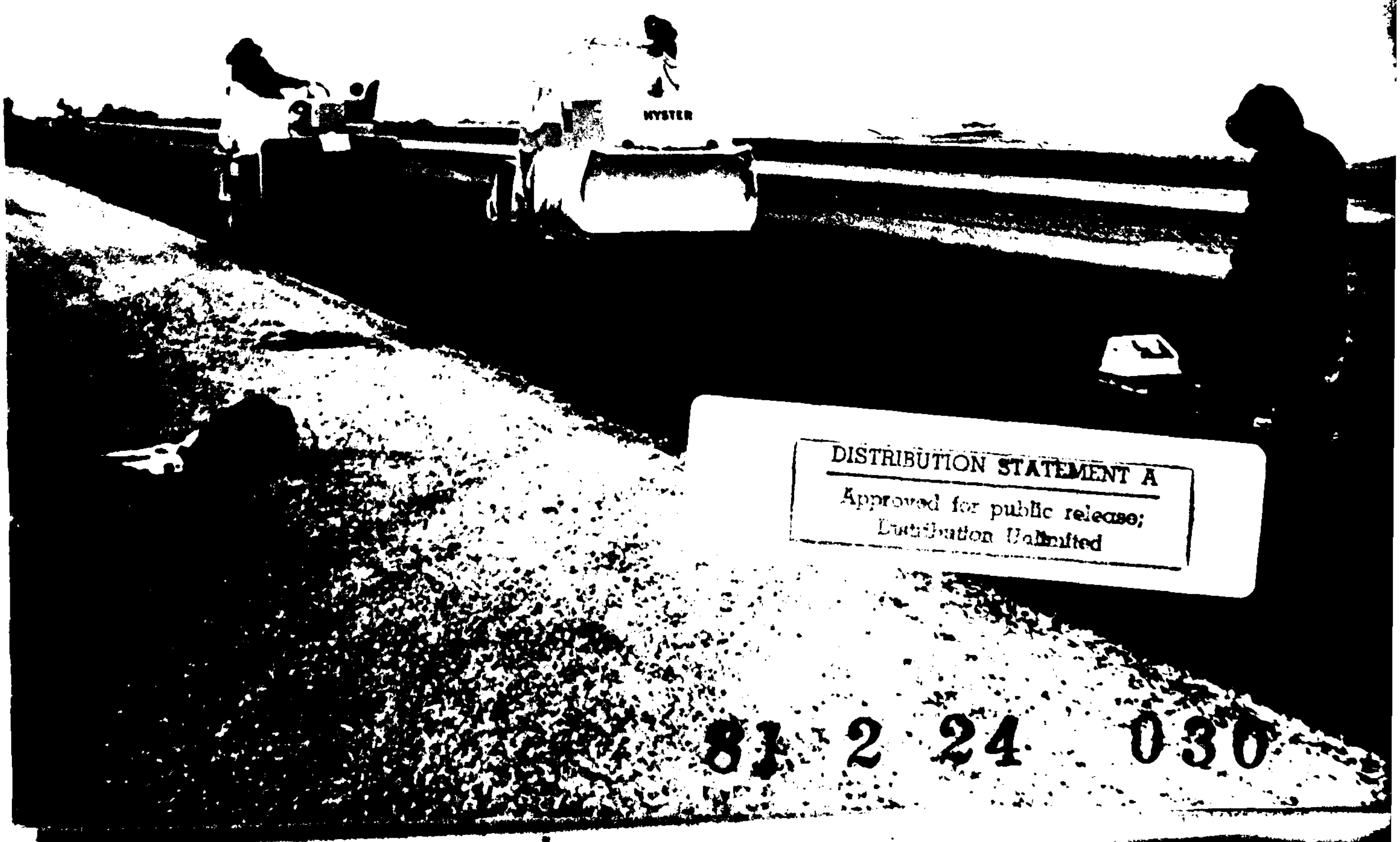

Cover: *Placing asphalt concrete pavement at Deadhorse Airport, Prudhoe Bay, Alaska. (Photograph by Jonathan Ingersoll.)*

CRREL Report 80-30

Field cooling rates of asphalt concrete overlays at low temperatures

R.A. Eaton and R.L. Berg

December 1980

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Six overlay test sections were placed on an existing test road in Hanover, New Hampshire, to gain experience in compaction of asphalt pavements at rolling temperatures as low as 150°F. The asphalt cement and aggregate used had mix characteristics similar to those of the mix expected to be used for a proposed overlay project at Thule Air Base, Greenland. Results of the overlay tests showed that computer-modeled cooling curves can be accurate predictors of the actual asphalt overlay cooling with time. In addition, the effects of temperature upon compaction were determined and it was found that nuclear gauges, when used and calibrated properly, successfully monitored mix density changes during compaction.

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PREFACE

This report was prepared by Robert A. Eaton and Dr. Richard L. Berg, Research Civil Engineers, of the Geotechnical Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by DA Project 4K078012AAM1, *Facilities Investigations and Studies Program,* Work Unit 102, *Evaluation of AC 2.5 Field Performance.*

North Smith and Thaddeus Johnson of CRREL technically reviewed this report.

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
mile/hour	0.44704*	meter/second
ton	907.1847	kilogram
pound/foot^3	16.01846	kilogram/meter^3
poise	0.1*	pascal second
centistoke	0.000001	meter^2/second
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius

*Exact.

FIELD COOLING RATES OF ASPHALT CONCRETE OVERLAYS AT LOW TEMPERATURES

R.A. Eaton and R.L. Berg

INTRODUCTION

Background

In 1975 the U.S. Air Force requested the New York District of the Corps of Engineers to develop plans and specifications for overlaying the runway at Thule Air Base, Greenland. Due to the unique environmental characteristics of Thule (permafrost, short construction season, low air temperatures, etc.), the District enlisted the assistance of CRREL and the U.S. Army Engineer Waterways Experiment Station (WES) in developing the asphalt overlay design. An airfield evaluation program was completed during the 1976 summer (Berg in prep.).

In 1976 the Corps of Engineers changed its requirement for selection of asphalt cements for use in cold regions (U.S. Department of the Army 1976). These new specifications required use of a select grade of AC 2.5 for the work at Thule. The penetration at 77°F was specified to be at least 290, and the minimum required kinematic viscosity was a value providing a pen-vis number (McLeod 1972) of at least -0.2. Lack of Corps experience with AC 2.5 asphalt concrete and the likelihood of cold weather paving at Thule led CRREL to recommend construction of an overlay test section on a pavement whose surface temperature was between 30° and 40°F. (Corps specifications required that asphalt not be placed when the surface temperature of the existing pavement or base course is below 40°F; this temperature was eventually reduced to 35°F for the Thule work.) Based on a study by Foster (1970), it is generally accepted that conventional asphalt pavement mixes are not compactable below about 175°F and that achievable field compaction times vary between 8 and 15 minutes. However, recent experience at the James Bay Hydroelectric Project in Quebec with an asphalt cement similar to that proposed for Thule indicated that the AC 2.5 could be compacted at mix temperatures below 175°F.*

On 18 November 1976, six overlay test sections using a grade of AC 2.5 similar to that proposed for the Thule mix design were constructed upon a test road in Hanover, New Hampshire.

Objectives

The objectives of this study were to:

1. Gain experience in handling and placing an AC 2.5 pen-vis specified asphalt concrete
2. Determine whether rolling would be effective once the overlay had cooled to 175°F
3. Validate computer-predicted cooling curves for asphalt concrete overlays during cold weather.

DESIGN AND CONSTRUCTION

In November 1976, four 100-x 12-ft x 3-in. and two 80-x 12-ft x 1½-in. overlay test sections were designed and placed between stations 1+10 and 3+90 (Fig. 1) on the CRREL Access Road (Berg and Eaton 1974). Prior to placement of the overlay, the surface was swept with a tractor-mounted power broom and pre-overlay cracks were mapped (Fig. 2). An AC 2.5 tack coat was hand-spread over the surface.

*Personal communication with A. Dion, Savriol et Assoc., Montreal, Canada, 1976.

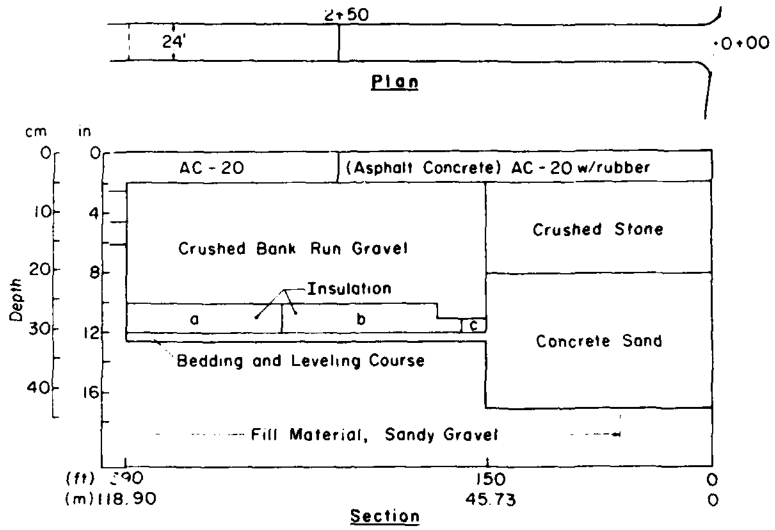


Figure 1. Plan and profile view of CRREL Access Road prior to placing the overlay.

The mix design was prepared by the Corps of Engineers, New England Division and the U.S. Army Engineer Waterways Experiment Station (WES). The AC 2.5 viscosity graded asphalt cement had properties nearly the same as the asphalt cement purchased for the work at Thule. The properties of the asphalt cement used in the test sections are shown in Table 1.

Aggregate selected was a local crushed bank run gravel which was thought to have characteristics similar to those of the aggregate available at Thule.

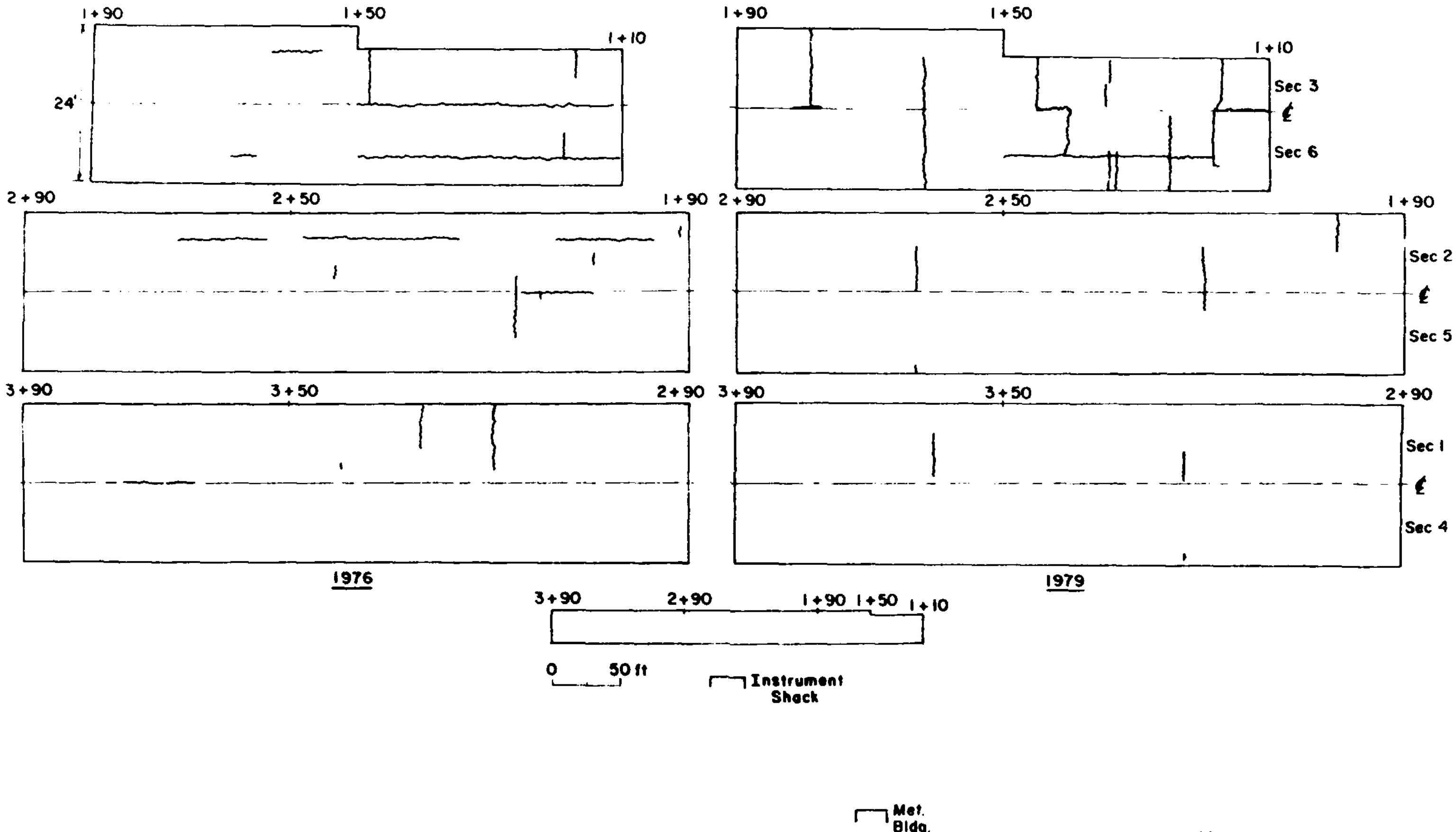
The construction contract required that the mixture be delivered to the job site at temperatures between 300° and 315°F. The contractor expressed considerable concern about this requirement because he had accomplished a project for the Vermont Department of Highways using AC 5 mixed at 250°F, which had separated from the aggregate during transportation at higher temperatures. For these test sections, this risk was minimized by delivering only sufficient material for the first test section before mixing the remainder of the material. Temperatures of the mix on each truck were measured with a hand-held bimetallic dial thermometer before the mix was dumped into the paver. Temperatures ranged from 300° to 310°F. Since no segregation problems were encountered with the mix, the same mixing temperature was maintained for the other test sections. Although the asphalt concrete in each of the six test sections was placed at approximately the same temperature, rolling did not commence until the mat had cooled to specified temperatures in each of the sections.

Table 1. Typical properties of AC 2.5 (300/400 grade) asphalt cement.*

Test	*Results*
Specific gravity	1.0183
API gravity	7.5
Water	Free
No foaming when heated to 347 F	Free
Viscosity, 140 F (poises)	277
Kinematic viscosity, 275°F (centistokes)	168
Spot test (T-120)	Neg.
Pen-vis number	+0.1
Flash point (COC) (°F)	630
Penetration at 77°F, 100 g, 5 sec	328
Solubility in trichloroethylene (%)	99.95
Tests on residue on thin film oven test:	
Viscosity, 140 F (poises)	448
Ductility, 77°F (5 cm/min)	>100
Loss in weight (%)	0.010
Penetration, 77°F, 100 g, 5 sec	183

*Personal communication with W. MacDonald, Petrolina, 1976.

To eliminate differences in compaction due to different types of rollers, the construction contract for the test sections required that tandem, 10-ton steel-wheeled rollers be used. The two rollers used on the test sections were nearly identical in size, weight and configuration.



a. Pre-overlay cracking, 1976.

b. Overlay cracking, 1979.

Figure 2. Pre-overlay and overlay cracking.

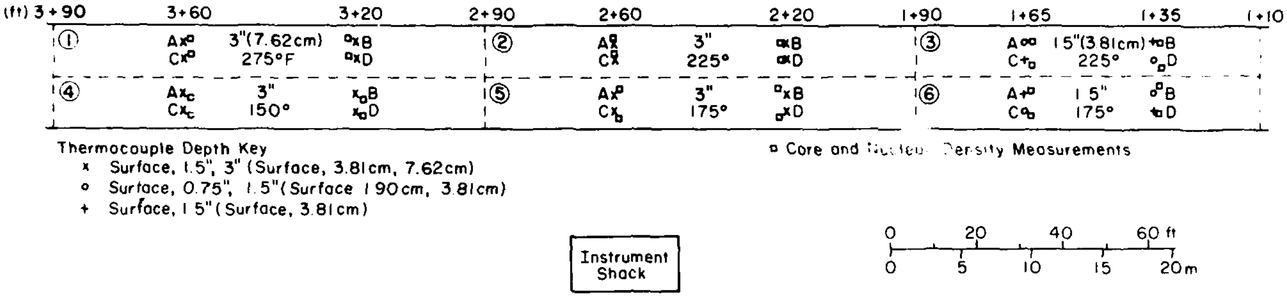


Figure 3. Density and temperature measurement locations.

Table 2. Design and actual thicknesses and temperatures at which rolling was initiated.

Section	*Design thickness (in.)*	*Actual thickness* (in.)*	*Rolling temperature (°F)*
1	3	2.80	275
2	3	2.80	225
3	1½	1.39	225
4	3	3.09	150
5	3	2.69	175
6	1½	1.78	175

*Average thickness from cores.

After rolling had been comp' ted with the steel-wheeled rollers and the mat h . cooled below 100°F, a rubber-tired roller was used ı an ineffective effort to seal some of the small tears (hairline cracking or checking) that occurred in the pavement surface in test sections 1 and 2. The rubber-tired roller was not used on the thinner mat in sections 3 and 6.

At four locations in each test section, thermocouples were installed within the overlay (Fig. 3). Temperatures were measured every two minutes using a data system located in an adjacent building. Nuclear gauges were used to measure changes in density after successive passes of the roller. Points for observing changes in density were located near each thermocouple array (Fig. 3).

Table 2 shows the overlay design thickness and temperature at which rolling commenced for each test section. The 3-in.-thick sections were placed in the following order: 1, 2, 4 and 5. After the 3-in.-thick sections were completed, the 1½-in. sections (3 and 6, respectively) were placed.

For overlay thickness determinations, rod and level surveys were conducted prior to and after the overlay was placed. Cores taken from the pavement were also used to verify the "as built" overlay thicknesses.

RESULTS AND DISCUSSION

Density studies

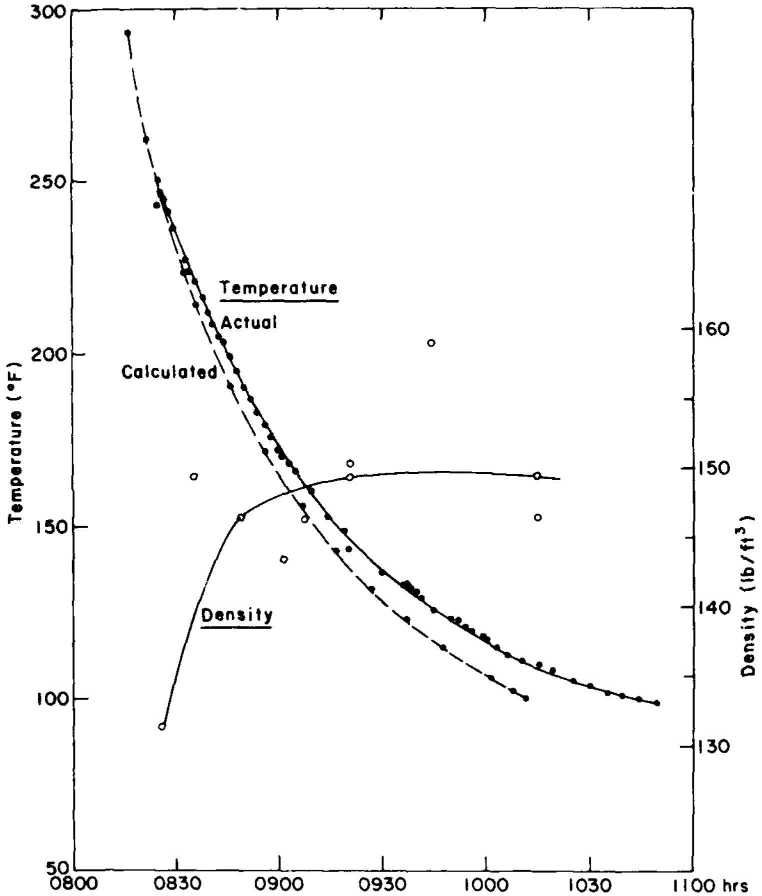
Nuclear density gauges were used at four different test points per section to determine overlay density changes after each roller pass. Measured and calculated cooling curves are shown in Figure 4.

In December 1976, 4-in.-diam cores were taken from each of the four nuclear density locations in each of the six test sections (Fig. 3). The cores were used to obtain final thickness and density measurements for each of the test locations (Table 3). The cores also provided checks on the nuclear density measurements. All the cores were taken through the full thickness of the overlay, including the tack coat.

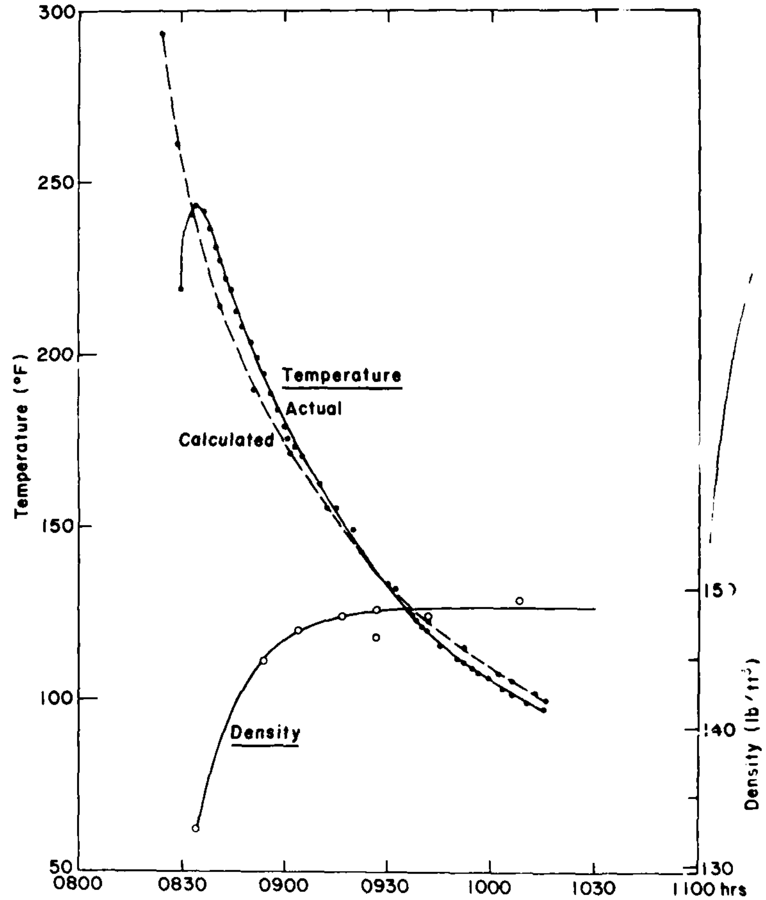
Data in Table 3 indicate that the average density of the test sections decreased as the temperature at which rolling commenced decreased. Also, the average densities of the thinner test sections were lower than those of the thicker test sections for similar initial rolling temperatures. The thinner sections did not contain the same amount of heat as the thicker sections and thus reached a temperature below which rolling was ineffective more quickly (Fig. 4).

Nuclear gauge data from sections 1 and 4 exhibited some scatter, due primarily to operator inexperience and difficulty in consistent positioning of the radioactive source in the same location when making an observation.

Operators of the nuclear density gauges counted the number of roller passes applied over each of the test points. Data points shown in Figures 4a–f represent

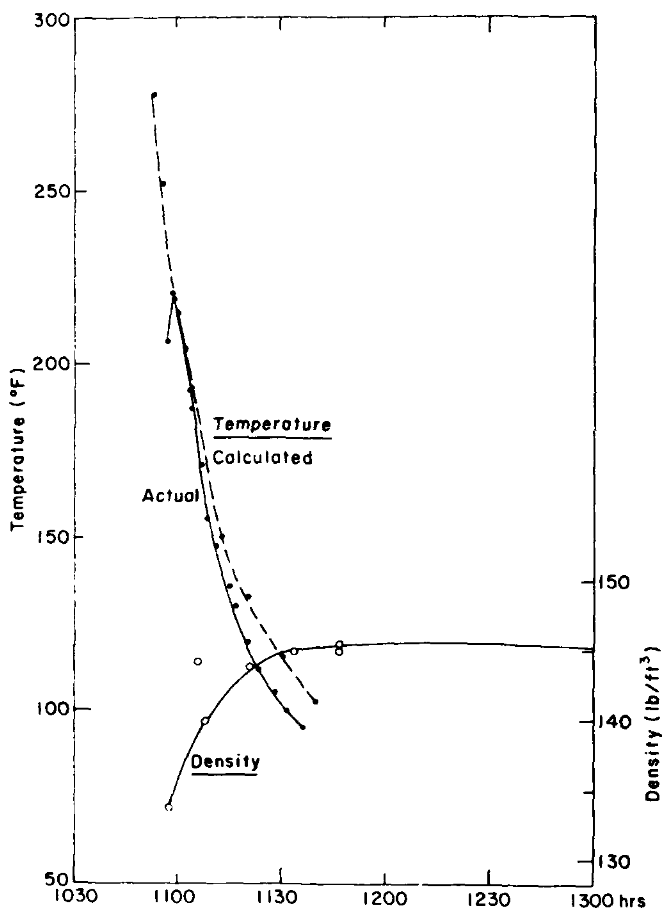


a. Section 1.

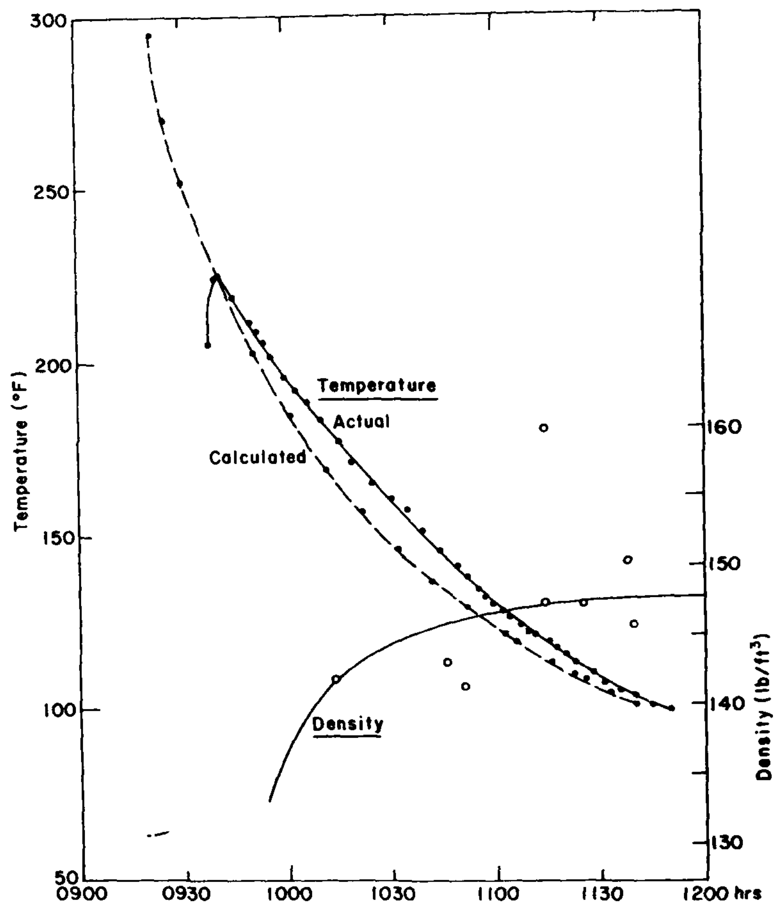


b. Section 2.

Figure 4. Measured and calculated cooling curves and construction densities for the six overlay test sections.

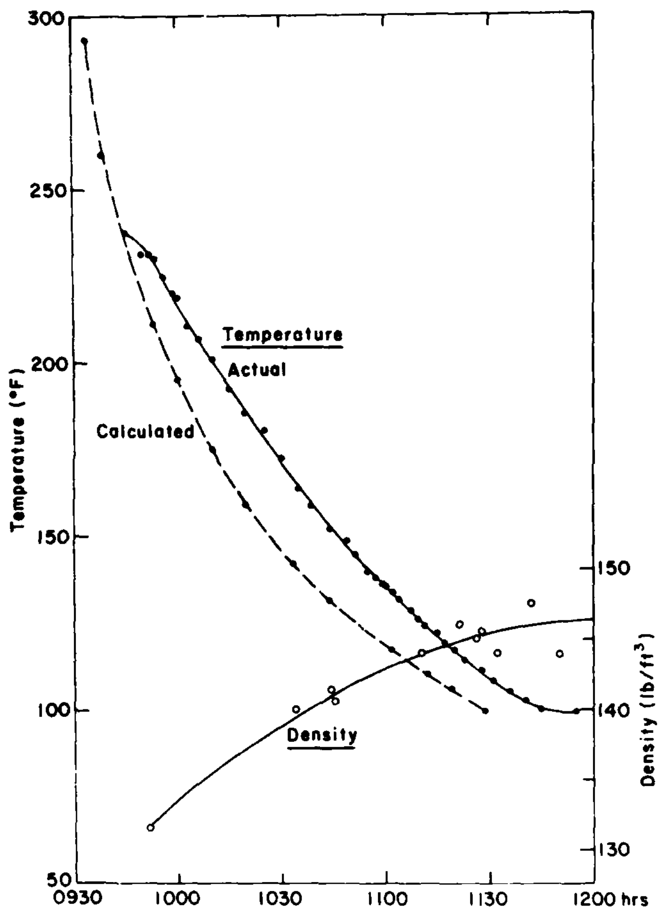


c. Section 3.

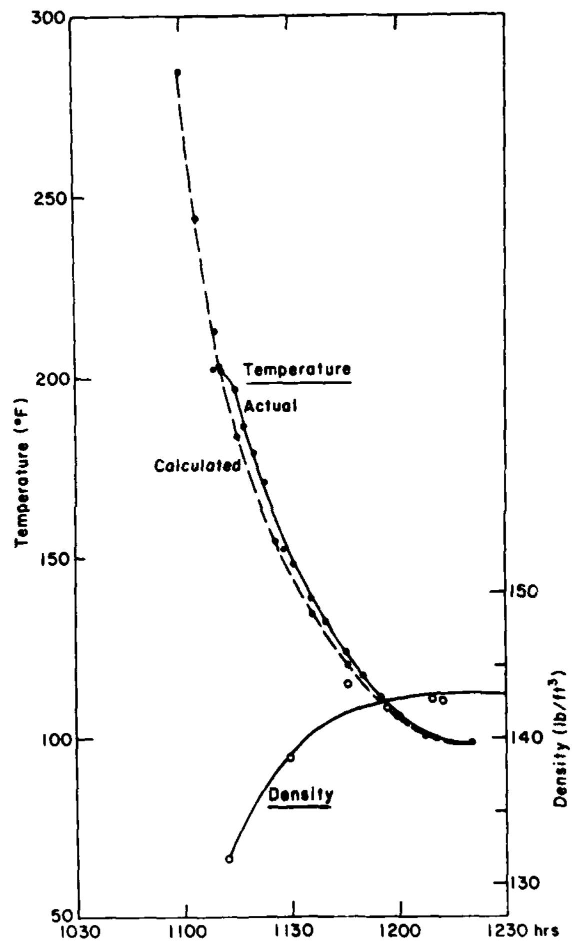


d. Section 4.

Figure 4 (cont'd). Measured and calculated cooling curves and construction densities for the six overlay test sections.



e. Section 5.



f. Section 6.

Figure 4 (cont'd).

Table 3. Densities and thicknesses of overlay from cores.

Test section	Rolling* temperature (°F)	Field density (lb/ft^3) at test point A	B	C	D	Avg.	Laboratory density	% of lab maximum	% Design density	Avg.† thickness (in.)
1	275	148.4	147.9	149.6	148.1	148.5	151.3	98.1	98.9	2.80
2	225	148.8	146.4	147.5	146.0	147.2	149.7	98.3	98.0	2.80
3	225	143.7	146.0	142.2	146.3	144.6	149.7	96.6	96.3	1.39
4	150	144.0	144.2	142.8	143.0	143.5	145.0	99.0	95.5	3.09
5	175	145.9	145.1	146.7	143.5	145.2	146.4	99.2	96.7	2.69
6	175	143.9	144.1	141.7	139.3	142.2	146.4	97.1	94.7	1.78

*Average overlay temperature at commencement of rolling.
†Cores were 4-in.-diam × the full thickness of the overlay at that point.

Table 4. Final corrected densities from nuclear density gauges.

Section	Density (lb/ft^3) at test point* A	B	C	D	Average
1	144.3	152.5	149.6	151.3	149.4
2	147.2	148.9	149.6	149.4	148.8
3	142.1	148.9	144.9	145.6	145.3
4	144.3	140.8	154.1	151.9	147.8
5	148.7	145.1	143.6	147.9	146.3
6	143.8	142.8	143.6	141.6	143.0

*Corrected densities were obtained by using section 1, point C for "calibration." The uncorrected density of 1C was obtained by using the calibration curve for the nuclear density gauge and the actual density was obtained from the 1C core. Densities for the remaining points were obtained by computing the uncorrected density of each point, and then adding the correction factor, which is the difference between the uncorrected density of 1C and the core density from 1C.

the average values for all four test points in each section after each pass of the roller.

The maximum AC 2.5 pavement density based on laboratory compacted samples (75 blows) of the mixture obtained from trucks was 150.2 lb/ft^3 at 250°F. A density of 147.2 lb/ft^3 would then be considered the minimum acceptable density under existing Corps of Engineers airfield pavement specifications, which require 98% of the laboratory density. Using this criterion, only test sections 1 and 2 would have been acceptable for an actual airfield overlay project. In the other four test sections, in-place densities were not at least 98% of the design density. Only 10-ton tandem steel-wheeled rollers were used in the tests to permit a direct comparison of the influence of roller coverages on each section. Higher densities might have been achieved on all of the test sections if a "normal" rolling pattern with a "normal" series of rollers had been used.

Table 4 contains final "corrected" measurements obtained with the nuclear density gauges. Since there was very little traffic on the roadway, these densities can be compared to those obtained slightly later from cores at essentially the same locations (Table 3). With the exception of section 4, the average densities obtained with the nuclear devices were generally 1½ lb/ft^3 greater than the core densities.

The large discrepancy in the average density for section 4 was caused by very high nuclear gauge readings at points C and D. The errors here were attributed to inconsistent positioning of the nuclear gauge radioactive source by an inexperienced operator.

Technicians at CRREL sampled the mix from several trucks and used the material to compact Marshall specimens (75 blows) at temperatures ranging from 90° to 275°F (Fig. 5). The resulting curve exhibits a relatively constant slope at temperatures down to about 120°F; then the slope becomes much greater and the change in density for a given change in temperature increases dramatically. Based on results shown in Figure 4, it appears that field densification did occur at temperatures down to 150°F; however, when rolling commenced

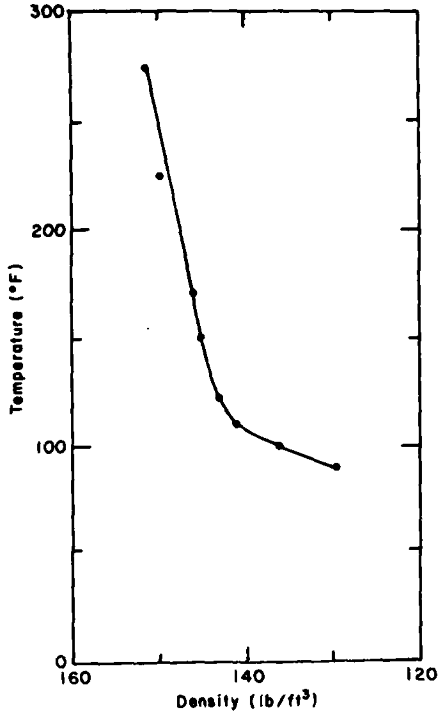


Figure 5. Laboratory AC 2.5 density.

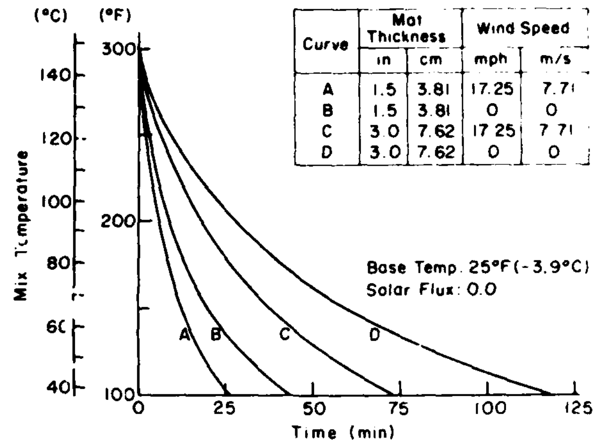


Figure 6. Calculated cooling curves.

at this temperature or at 175°F, an acceptable density was not achieved. Data from Table 3 indicate that a 3-in.-thick overlay was compacted to an acceptable density when rolling was started at 225°F or higher. Although only two data points were obtained for the 1½-in.-thick overlay, extrapolating the information on an arithmetic plot indicates that rolling should have commenced at about 275°F to achieve adequate compaction of the 1½-in.-thick overlay.

Estimated cooling rates

A computer program, modified from the Federal Highway Administration (FHWA) version (1972) of the original Corlew and Dickson (1968) computer model, was used to calculate "cooling curves" for each of the test sections. The FHWA program was developed to determine the time required for an asphaltic concrete pavement to cool to an average temperature of 175°F. It required the following input parameters: base temperature, mix temperature, incident solar radiation, air temperature, mat density, mat thickness, and wind velocity. The program was modified at CRREL so that the average temperature of the mixture was computed as a function of time. Based on the results of this cooling curve, one can determine the time available for rolling to achieve compaction, i.e. the predicted time for the average temperature of the mat to reach a selected temperature under given environmental conditions. Input and output from the FHWA program were also modified slightly for these studies.

All of the parameters required as input to the computer program were measured at the site. Since construction was initiated early in the morning, the quantity of incident shortwave radiation and the surface temperature changed considerably during the course of the tests. The wind speed also varied. Representative values of each parameter for the time period of the particular test section are shown in Table 5. These data were used as input to the computer model. Measured and calculated cooling curves for all of the sections are shown in Figure 4a–f, in which the calculated data agree closely with measured temperatures.

To further illustrate the influence of environmental conditions upon cooling rates, the computer program was used to produce data for Figure 6. As shown in this figure, a 3-in.-thick overlay placed at 300°F on a base whose temperature is 25°F (curve D) will cool to 150°F in 60 minutes with no wind and no direct incoming solar radiation (overcast). However, it will reach this same temperature in only 37 minutes if the wind is blowing at 17.25 mph (curve C).

Given a base temperature of 25°F, if the overlay thickness is only 1½ in. (curve B), it will cool to 150°F in 20 minutes or in one-third the time of the 3-in.-thick

Table 5. Input data for computer simulations.

Test section	Short wave radiation (BTU/ft² hr)	Mat thickness* (in.)	Mat density† (lb/ft³)	Base temperature (°F)	Mix temperature (°F)	Air temperature (°F)
1	27	2.80	148.5	28	305	30
2	28	2.80	147.2	28	305	30
3	114	1.39	144.5	43	305	44
4	52	3.09	143.5	32	305	36
5	57	2.69	145.2	33	305	38
6	108	1.78	142.2	43	305	44

*Average thickness from cores.
†Average density from nuclear density tests.

Table 6. Reflection cracking.

Station	Section	Overlay thickness (in.)	1976 pre-overlay cracks (linear feet)	1979 post-overlay cracks (linear feet)
2+90 to 3+90 W of CL	1	2.80	22	23
1+90 to 2+90 W of CL	2	2.80	67	27
1+10 to 1+90 W of CL	3	1.39	40	49
2+90 to 3+90 E of CL	4	3.09	6	14
1+90 to 2+90 E of CL	5	2.69	13	6
1+10 to 1+90 E of CL	6	1.78	68	80

mat with no wind and no direct incoming solar radiation (curve D). If a 17.25-mph wind is blowing, the 1½-in. mat will cool to 150°F in 12 minutes (curve A), again approximately in one-third the time for the 3-in. mat under similar environmental conditions (curve C).

This underscores the importance of thickness upon cooling rates and emphasizes the importance of breakdown rolling to obtain proper densities as soon as possible after placement.

Cooling rates will, of course, fluctuate as the environmental conditions vary, but these examples were presented as being typical of conditions which may be encountered in the northern United States, on the Alaskan North Slope, or in Greenland.

GENERAL DISCUSSION

After the first year of use, no reflection cracking had occurred in the 3-in overlay sections (1, 2, 4, and 5), but most of the cracks had reflected through the 1½ in. overlay of sections 3 and 6. Reflection cracking was again mapped in 1979 (Fig. 2), and then tabulated by section for comparison with the amount of pre-overlay cracking (Table 6).

Sections 3, 4, and 6 were originally compacted at less than 145 lb/ft³, and after three years they showed the most reflection cracking with an average of 158%. Section 1 showed 100% cracking. This is attributed to the hot mix temperature of 275°F which caused some roller cracking (checking) during compaction. For this AC 2.5 mix, it is apparent that the mat should cool below 250°F before rolling, or the mix temperature should be 260°F ± 10°F at the plant to prevent mat checking or tearing during compaction.

The cause of transverse post-overlay cracking of sections 1, 2, 4, and 5 can be correlated with the thermocouple wires placed in the pavement to measure temperature changes.

CONCLUSIONS

The AC 2.5 asphalt cement used in this test had a pen-vis number (PVN) of +0.1. No problems were encountered when it was mixed with locally available crushed bank-run gravel. The mixture was delivered to the site at 300° to 315°F and no separation of the asphalt cement from the aggregate was observed. Hairline cracking or checking did occur on the 3-in. thick sections when compaction was started at average mat temperatures above 250°F. Therefore, either the mat temperature should be less than 250° before compacting, or the mix temperature should be 260° ± 10°F at the plant.

Cooling curves computed using a model similar to that originally developed by Corlew and Dickson (1968) agreed closely with those measured during the test.

The relationship between the asphalt concrete temperature when compaction is initiated and the final density of an overlay can be accurately estimated by compacting Marshall specimens at a range of temperatures. Laboratory results in this test indicate that compaction will continue at temperatures as low as 150°F. However, results from both the laboratory and field tests show that, if compaction is initiated at these low temperatures, adequate overlay densities will not be achieved.

Information obtained from laboratory tests similar to those used in this study and from computed cooling curves should be useful in the proper selection of compaction equipment and in estimating the time available to obtain the required density.

Both the cooling curves (Fig. 6) and field test results (Fig. 4) illustrate that less than 20 minutes may be available to adequately compact a relatively thin overlay when the air and surface temperatures are near 32°F.

In general, nuclear gauges successfully monitored changes in density of the mix as it was compacted. The need for qualified operators became apparent during tests due to problems in consistently positioning the nuclear source of one gauge. Proper daily calibration of the gauges is essential.

After more than three years, most of the cracks that have appeared in the 3-in.-thick overlay sections can be attributed to the thermocouple wires placed in the overlay to measure temperatures. In the 1½-in. overlay sections, however, nearly all of the cracks have reflected through the overlay.

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