Constructing Longitudinal Joints In Hot-Mix Asphalt Pavements

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This paper presents results of density and tensile strength test of samples cut from longitudinal joints in hot-mix asphaltic pavement. An unanticipated finding is that in semi-hot and cold joints there is a low-density zone at the joint in the lane paved first and a high-density zone at the joint in the lane paved subsequently. These zones are not present in hot joints made with pavers operating in echelon. These low- and high-density zones may well be the basic problem in constructing durable longitudinal joints in asphalt pavements.

•JOINTS are often the weakest portion of a bituminous concrete surfacing and under unfavorable conditions of exposure and/or construction, visible defects may occur first at the joints. These defects may allow the ingress of water into the pavement leading to further disintegration (Fig. 1). This paper presents density and tensile strength of longitudinal joints made by several methods.

A search of the literature revealed no pertinent information on the subject. Therefore, standard specifications of the various States were used as references on joint construction techniques.

Hot Joints

These are produced with pavers operating in echelon spaced close enough together so that the lane placed first does not cool significantly before the second lane is placed. There is no special treatment of the face of the joint placed first. Rolling techniques can be "pinched" or "overlapped".

Semi-hot Joints

These are produced when a restriction is placed on the distance a paver may proceed before setting back and bringing up the adjacent lane to match the first lane. Generally the material in the first lane cools to approximately 120 to 140 F before the adjacent lane is placed.

First Lane.—The edge of the first lane, which will be a face of the joint, may be compacted during rolling of the first lane prior to placing the second lane, or a strip approximately 6 in. wide may be left uncompacted until the subsequent lane is placed and rolled. Usually, there is no treatment of the edge of the first-laid lane, although in some instances, a tack of cut-back or emulsion may be required.

Subsequent Lane.--In placing the subsequent lane, the paver may be operated to butt the joint or it may overlap the first lane 2 to 4 in. The overlapped material may be scooped up with a shovel to a neat line at the joint, swept back on the hot lane, or pushed

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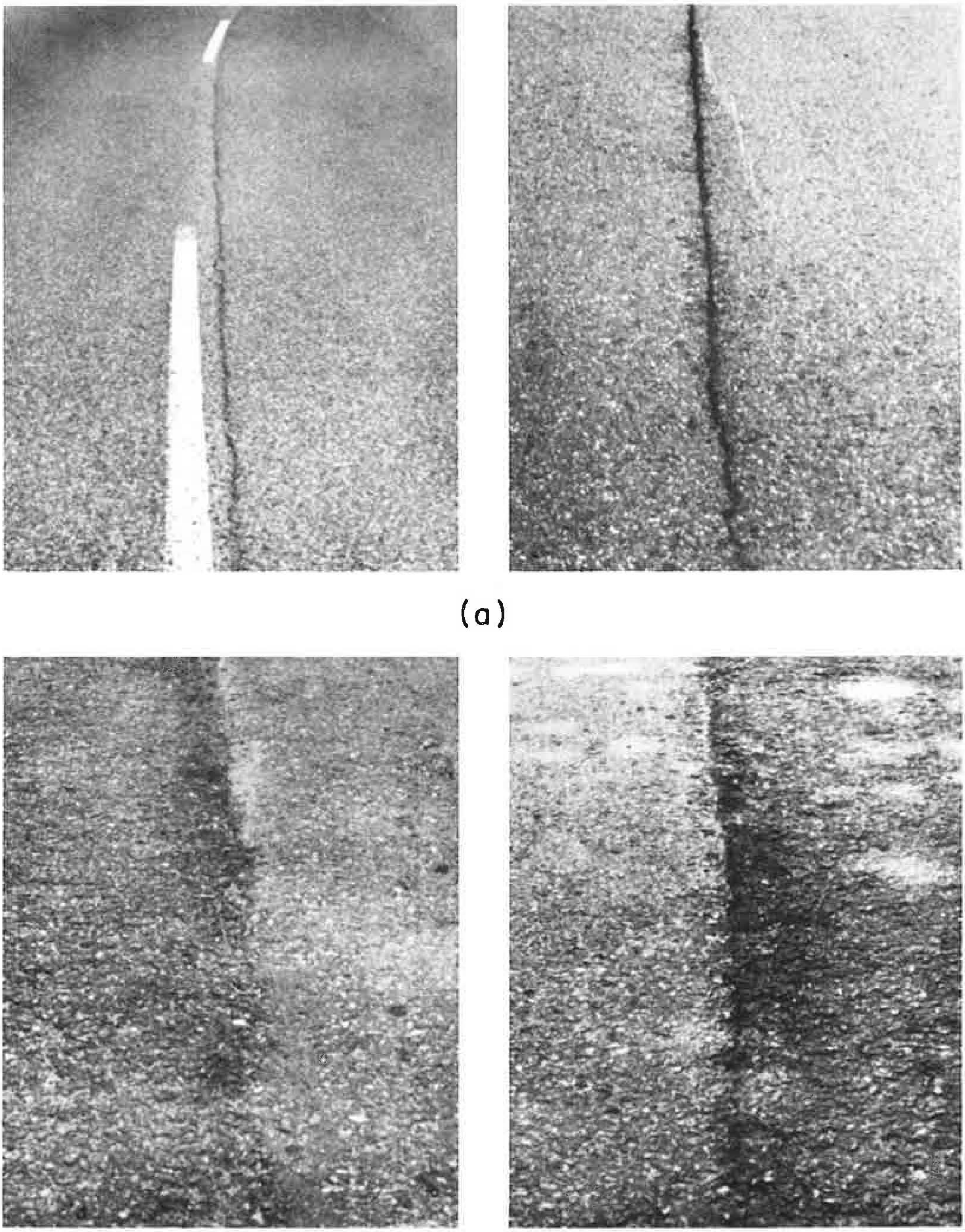


Figure 1. Visible defects at joints: (a) center line cracking, and (b) center joint raveling.

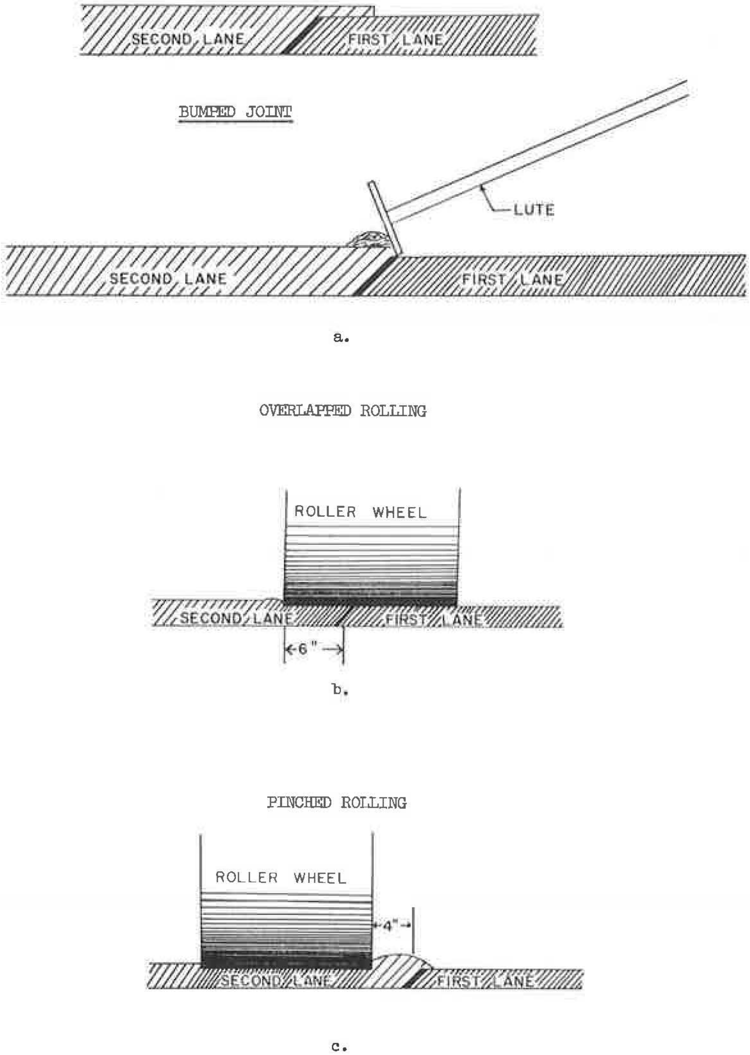


Figure 2.

back with a lute creating a bump (Fig. 2a). In the latter case, the overlap must be adjusted so that the roller can crowd the bump into the joint. Rolling may be started from the first lane overlapping the subsequent lane by about 4 in. (Fig. 2b) or on the subsequent lane pinching the material into the joint (Fig. 2c).

Cold Joints

These occur where the first lane has cooled overnight or longer before the next lane is placed or where the first lane is carried so far ahead that the face has cooled to well below 120 F.

First Lane.—The edge of the first lane, which will be a joint, is always compacted during rolling of the first lane. The edge may be left in this condition before placing the second lane or it may be cut back with a saw or a wheel to produce a fresh face. Saws are used to produce a vertical face. The wheel cutter may be operated to produce a face 30° from the vertical. The edge of the first lane may also be tacked or left

untacked. In recent years, infrared heaters have been used to heat the joint before placing the subsequent lane.

Subsequent Lane. —Placement and rolling procedures are the same as those for semi-hot joints.

TABLE 1

TYPICAL MIX COMPOSITIONS

Mix	Passing Sieve (%)									Asphalt Content[a] (%)	Marshall Criteria			
	5/8 in.[b]	1/2 in.[b]	3/8 in.[b]	No. 4[b]	No. 10[c]	No. 20[c]	No. 40[c]	No. 80[c]	No. 200		Stability (lb)	Flow (0.01 in.)	Voids (%)	Voids Filled
I-2	-	100	98	80	65	48	32	13	7[d]	6.25	600	9-16	4-10	-
PC-1-61	100	99	88	68	45	34	24	12.5	4.4[e]	5.6	1,200-2,500	10-17	2-5	75-85

[a]Penetration grade 85-100.
[b]Crushed stone.
[c]Screenings and sand.
[d]Natural fines and 3% fly ash.
[e]Limestone filler and natural fines.

TEST PROGRAM

North Carolina was selected as the initial location of these studies, but because the I-2 surface mix (Table 1) used is quite plastic at early ages at roadway temperatures, it was believed that many of the problems of longitudinal joint construction would not be present. Therefore, the study was moved to Maryland. Despite constant efforts to improve the procedure, some problems occur in longitudinal joint construction with the PC-1-61 surface mixed used in Maryland which is typical of mixes used in many sections of the United States.

Construction Methods

Hot Joints. —Hot joints studied in Maryland were made with pavers operating in echelon. The joint between the two lanes was rolled by overlapping. This method normally produces very satisfactory joints and was included as a basis of comparison.

Semi-hot Joints. —The semi-hot joint is not normally permitted in Maryland and was simulated for this case on a job where pavers were being operated in tandem by placing one lane approximately 700 to 800 ft in advance of the second lane. This resulted in temperatures ranging from 120 to 140 F at the joint side of the initial lane at the time the second lane was placed. At two locations, the initial lane was uncompacted; that is, it was not rolled to the edge before placing the second lane. This condition was studied with the joint face tacked and untacked. In all other instances, the initial lane was compacted or rolled to the edge before placing the second lane. This condition was studied with joints pinched, bumped or overlapped; for each method the joint face was tacked and untacked.

Cold Joints. —Cold joints studied in this investigation were constructed by allowing the first lane to cool overnight before the second lane was constructed. Temperature of the face of the joint for the initial lane was approximately 60 to 75 F in the North

Carolina tests and 35 to 45 F in the Maryland studies. In all instances, the initial lane was rolled to the edge before placing the second lane.

Joint Trimming. —Longitudinal joints are trimmed to remove uncompacted, low density material and present a clean, firm face for contact with the paving material placed for the adjoining lane.

The edge of the lane was wheel cut with a unit attached to a grader. This was found to be difficult because the operator could not see the wheel mounted in front of the blade and the large pneumatic tires caused unsteadiness. Such a device mounted on a steel-wheeled roller may be more successful and provide a quick method of making a smooth, continuous cut. Rollers are also more readily available than graders on the average project.

Joints were cut back with a concrete saw for the purpose of comparison. Except in unusual circumstances, saw cutting is not practicable.

All joints in this study were cut to a vertical face. Trimming at an angle somewhat off the vertical might have some value but was not studied in this investigation.

Joint Heating. —Of cold joints constructed using infrared heating, 12 samples were taken from the Capital Beltway in Maryland and 6 samples were obtained from North Carolina.

During the application of heat to the cold joints, it was noted that a pencil could be pushed easily more than $\frac{1}{2}$ in. into the heated material. The 8-ft long heating device was attached to the side of a paver and maintained $1\frac{1}{2}$ in. above the pavement surface. It successfully softened the pavement to a depth of approximately $\frac{3}{4}$ in. for a width of approximately 4 in. at the edge of the cold lane.

Weather and Construction Conditions

Maryland. —Pavement laid under the adverse conditions of late fall is normally more prone to longitudinal joint failure. In recognition of this, the Maryland tests were made in November when ambient temperatures during paving operations ranged from 40 to 50 F and during the cold-joint studies, in which the first lane was allowed to cool overnight before the laying of the second lane, the temperature dipped slightly below the freezing mark. The single exception was the hot-joint construction done on October 24, with the maximum ambient temperature of 54 F.

Hot and semi-hot joint samples were taken from the $1\frac{1}{2}$-in. overlay of PC-1-61 surface course on the eastbound lane of Route 40 in Maryland, approximately 12 mi east of Baltimore. This is a portland cement concrete 4-lane dual highway, carrying an average ADT of more than 27,000 vehicles with 14 percent heavy trucking.

Samples of cold joints were obtained from the Capitol Beltway which encircles the city of Washington, D. C. The cut-off date for paving had already passed when permission was granted by Maryland State Roads Commission to conduct research at this location. A special paving extension was authorized and the paving contractor cooperated in the various construction techniques involved.

Breakdown rolling by both participating contractors was accomplished by use of a 2-wheel, 10 to 12 ton tandem roller, followed by rubber-tired rolling and finish rolling with a 3-axle tandem. Because the major problem appears to be the compaction of the free edge of the lane, the use of a 3-wheeled roller would probably not have greatly affected the findings. This is confirmed by the results of the North Carolina tests.

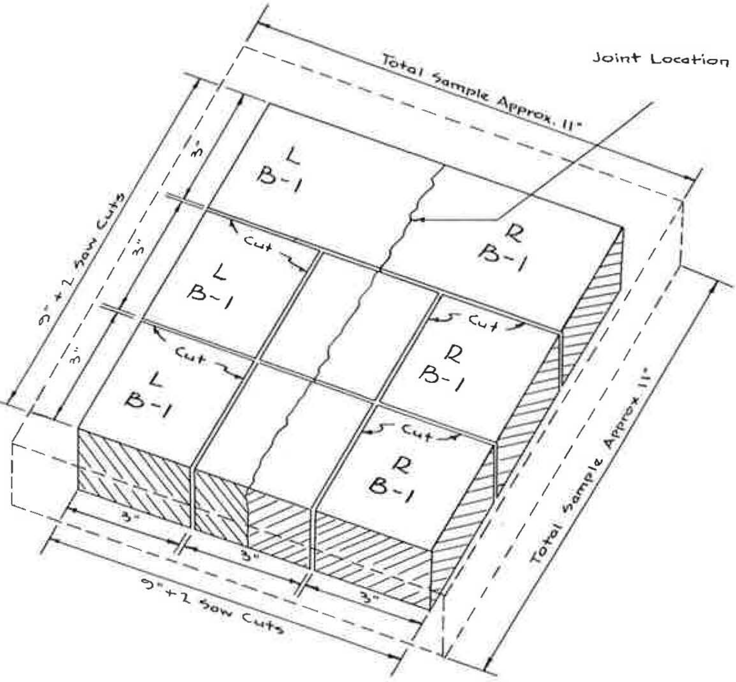
North Carolina. —The cold-joint samples were taken from the westbound lane of US 70 between Raleigh and Garner. This lane was constructed by reinforcing the existing asphaltic pavement with 3 in. of black base surfaced with two 1-in. courses of North Carolina I-2 mix. All samples were taken from the bottom course of I-2.

A 10 to 12 ton, 3-wheeled roller was used for breakdown, followed by a rubber-tired roller with about 60 psi contact pressure, and an 8 to 12 ton tandem for finish rolling.

All samples were taken the week of September 9, 1962. Although pavement temperatures were fairly low in the early morning, the I-2 surface mixture tended to become plastic when exposed to the heat of the Sun.

Sampling Procedure

All samples were taken from pavement laid under normal construction conditions.



SAMPLE CUTTING PROCEDURE

NOT TO SCALE

Figure 3.

Sections approximately 12 in. square were sawed at predetermined locations, each representing a particular method of joint construction. Locations were also established 6 ft on each side of the joint for comparative samples.

To avoid distortion of or damage to samples during removal, a plane of separation from the tacked surface being covered was provided by taping a sandwich of two layers of aluminum foil separated by one layer of kraft paper to the existing pavement. Sample locations were marked before paving and the exact joint location was carefully referenced immediately following the laying of the first lane. After sawing and removal, each sample was carefully marked with control number, joint location and left and right sides.

For transport from field location to the Maryland State Roads Commission Laboratory, the samples were securely taped, wearing surface down, to $^5/_8$-in. plywood pallets, 12 by 36 in., each holding three samples. All samples were stored on these pallets at room temperature (65 to 77 F).

Each large sample was cut into six 3- by 3-in. coupons (Fig. 3), two at joint location and two from each side, and one 3- by 9-in. coupon, with joint construction midway of the long measurement.

Tests Conducted

Density. —The 3-in. square coupons, representing the joint area and lane edges immediately on either side of this area, were used to determine densities (Table 2). The density of all Maryland samples was determined by the Maryland State Roads Commission Bureau of Materials and Research. Samples were weighted, uncoated, in air and water. Because of the character of this surface mix, practically no absorption

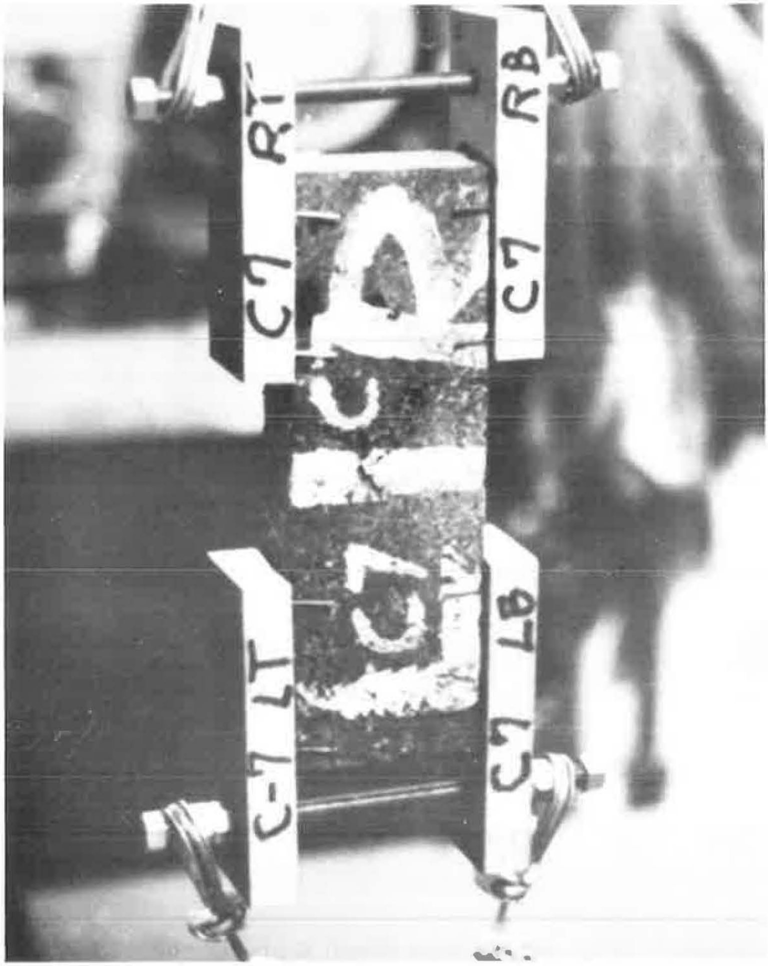


Figure 4. Sample in tensile test.

occurred and coating of the samples with wax was not considered necessary. The results of these tests were the basis for comparing densities within the 9 in. of joint construction area in three sections--left of, right of, and at the joint. In most cases, duplicate samples were available and the results of the two density tests were averaged to represent a given location. Density determinations were also made on lane samples taken 6 ft from the joint for comparison.

Tensile Strength. --Tensile strength tests of bituminous mixes are not a standard procedure but are not entirely without precedent. Massachusetts Institute of Technology used a similar method in testing mixes containing asbestos and some results of tensile tests are available in the literature.

To determine the optimum rate of loading and establish an effective means of applying the load, several 3- by 9-in. coupons of a similar mix were used for developing the test method. Wooden blocks, ¾ by 2 by 5 in., were glued to each of the sawed sides of the coupons with an epoxy-type black surfacing compound for pavements, leaving a 3-in. space between the ends of the blocks. These blocks extended approximately 2 in. beyond each end of the coupon and holes were bored to permit the insertion of a ⅜-in. threaded steel rod. By use of an attached cable yoke, these samples were then tested for tensile strength in a Universal machine (Fig. 4).

The rate of strain was 0.05 in./in./min. All samples were maintained at room

TABLE 2

DENSITIES OF HOT-MIX ASPHALT SAMPLES

Sample No.	Type of Joint	Density (pcf): Adjacent to Joint Unconfined Side	Joint	Adjacent to Joint Confined Side	Lane Samples
	Hot Joints - Maryland				
A-1	Overlapped Rolling	142.5	142.8	144.1	
A-2	Overlapped Rolling	144.5	144.6	143.0	
A-3	Overlapped Rolling		140.6		
A-4	Lane Sample for Comparison				137.9
A-5	Lane Sample - Density only				142.8
A-6	Lane Sample - Density only				147.0
	Semi-hot Joints - Maryland				
B-1	Not tacked, Not compacted	138.1	136.4	147.0	
B-2	Not tacked, Compacted, Pinched	139.0	141.6	147.0	
B-3	Not tacked, Compacted, Bumped	137.3	141.9	148.3	
B-4	Not tacked, Compacted, Overlapped	143.2	140.2	148.4	
B-5	Tacked, Not compacted	136.9	136.7	147.2	
B-6	Tacked, Compacted, Pinched	141.1	144.6	146.4	
B-7	Tacked, Compacted, Bumped	138.5	144.5	147.4	
B-8	Tacked, Compacted, Overlapped	143.8	139.7	148.7	
B-15	Not tacked, Compacted, Overlapped	143.8	141.2	141.2	
B-16	Not tacked, Compacted, Overlapped	145.8	146.2	145.3	
B-17	Lane Sample - Density only				140.4
B-18	Lane Sample - Density only				139.5
B-19	Lane Sample - Density only				144.5
B-21	Lane Sample - Density only				140.2
	Cold Joints - Maryland				
C-1	Not tacked, Compacted, Pinched	136.7	134.9	145.9	
C-2	Not tacked, Compacted, Bumped	137.6	137.9	142.0	
C-3	Not tacked, Compacted, Overlapped	136.5	140.4	147.6	
C-4	Tacked, Compacted, Pinched	140.0	140.3	146.9	
C-5	Tacked, Compacted, Bumped	137.1	140.7	145.3	
C-6	Tacked, Compacted, Overlapped	136.3	138.1	143.2	
C-7	Not tacked, Pinched, I-R Heated	137.5	135.8	143.7	
C-8	Not tacked, Bumped, I-R Heated	133.2	138.3	145.1	
C-9	Not tacked, Overlapped, I-R Heated	133.7	136.7	140.4	
C-10	Tacked, Pinched, I-R Heated	137.0	138.7	144.0	
C-11	Tacked, Bumped, I-R Heated	137.3	132.1	142.7	
C-12	Tacked, Overlapped, I-R Heated	136.8	131.8	140.9	
	Cold Joints - Maryland - continued				
C-13	Tacked, Compacted, Pinched, Sawed	139.4	140.3	145.6	
C-14	Tacked, Compacted, Bumped, Sawed	138.7	142.3	144.8	
C-15	Tacked, Compacted, Overlapped, Sawed	140.2	139.1	145.0	
C-16	Not tacked, Compacted, Pinched, Wheel Cut	138.3	138.1	145.7	
C-17	Not tacked, Compacted, Bumped, Wheel Cut	137.5	141.5	143.9	
C-18	Not tacked, Compacted, Overlapped, Wheel Cut	140.7	140.2	145.3	
C-19	Not tacked, Pinched, Sawed, I-R Heated	140.8	138.7	143.6	
C-20	Not tacked, Bumped, Sawed, I-R Heated	138.2	141.5	147.6	
C-21	Not tacked, Overlapped, Sawed, I-R Heated	140.1	138.7	143.0	
C-22	Not tacked, Pinched, Wheel Cut, I-R Heated	140.3	138.7	142.6	
C-23	Not tacked, Bumped, Wheel Cut, I-R Heated	137.1	142.5	147.0	
C-24	Not tacked, Overlapped, Wheel Cut, I-R Heated	139.5	138.2	144.7	
C-25	Tacked, Compacted, Bumped, Wheel Cut	139.3	135.3	139.3	
C-26	Tacked, Compacted, Overlapped, Wheel Cut	138.0	140.6	147.3	
C-27	Tacked, Compacted, Pinched, Wheel Cut	133.4	137.8	148.0	
C-28	Lane Sample for Comparison				144.6
C-29	Lane Sample for Comparison				145.[illegible]
C-30	Lane Sample for Comparison				144.6
C-31	Lane Sample for Comparison				138.[illegible]
C-32	Lane Sample for Comparison				145.3
C-33	Lane Sample for Comparison				144.0
	Cold Joints - North Carolina				
D-1	Tacked, Overlapped	125.5	125.9	129.5	
D-2	Not tacked, Overlapped, Bumped	126.1	131.2	131.2	
D-3	Not tacked, Overlapped	123.3	125.3	131.5	
D-4	Not tacked, Bumped	124.1	118.9	131.5	
D-5	Not tacked, Overlapped	125.5	127.9	132.0	
D-6	Not tacked, Overlapped, Bumped	122.7	123.7	129.7	
D-7	Not tacked, Overlapped	125.2	120.2	126.5	
D-8	Tacked, Overlapped, Bumped	121.7	121.6	130.5	
D-9	Tacked, Overlapped	122.7	126.1	129.5	
	Cold Joints - North Carolina - continued				
D-10	Tacked, Overlapped, Bumped	122.1	123.5	129.5	
D-11	Tacked, Overlapped	123.5	124.4	128.2	
D-12	Tacked, Bumped, Pinched	123.8	128.2	130.0	
D-14	Tacked, Bumped, Pinched	123.6	131.7	128.0	
D-15	Not tacked, Overlapped	126.5	125.4	131.0	
D-16	Not tacked, Overlapped, I-R Heated	127.9	126.8	130.6	
D-17	Not tacked, Overlapped	126.5	130.6	132.6	
D-18	Not tacked, Overlapped, I-R Heated	126.9	127.5	132.0	
D-19	Not tacked, Overlapped, I-R Heated	124.6	129.7	131.8	
D-20	Not tacked, Overlapped	126.4	132.1	133.5	
D-1c	Lane Sample for Comparison				124.0
D-7c	Lane Sample for Comparison				129.2
D-8c	Lane Sample for Comparison				124.6
D-14c	Lane Sample for Comparison				125.4

TABLE 3

MAXIMUM TENSILE STRENGTH OF HOT-MIX ASPHALT SAMPLES

Sample No.	Type of Joint	Maximum Tensile Strength (psi), Location of Failure: Adjacent to Joint Unconfined Side	Joint	Adjacent to Joint Confined Side	Indefinite	Lane Sample
	Hot Joints - Maryland					
A-1	Overlapped Rolling	11.0				
A-2	Overlapped Rolling			17.3		
A-4	Lane Sample for Comparison					9.7
	Semi-hot Joints - Maryland					
B-1	Not tacked, Not compacted		10.1			
B-2	Not tacked, Compacted, Pinched	13.5				
B-3	Not tacked, Compacted, Bumped		14.5			
B-4	Not tacked, Compacted, Overlapped		13.7			
B-5	Tacked, Not compacted			13.4		
B-6	Tacked, Compacted, Pinched		10.7			
B-7	Tacked, Compacted, Bumped		11.1			
B-8	Tacked, Compacted, Overlapped		13.3			
B-15	Not tacked, Compacted, Overlapped			12.5		
B-16	Not tacked, Compacted, Overlapped			14.3		
	Cold Joints - Maryland					
C-1	Not tacked, Compacted, Pinched	12.4				
C-2	Not tacked, Compacted, Bumped				17.1	
C-3	Not tacked, Compacted, Overlapped	9.3				
C-4	Tacked, Compacted, Pinched	17.1				
C-5	Tacked, Compacted, Bumped	14.2				
C-6	Tacked, Compacted, Overlapped	15.1				
C-7	Not tacked, Pinched, I-R Heated				15.9	
C-8	Not tacked, Bumped, I-R Heated	14.1				
C-9	Not tacked, Overlapped, I-R Heated	12.0				
C-10	Tacked, Pinched, I-R Heated	16.3				
C-11	Tacked, Bumped, I-R Heated				13.9	
C-12	Tacked, Overlapped, I-R Heated		11.1			
C-13	Tacked, Compacted, Pinched, Sawed		16.3			
C-14	Tacked, Compacted, Bumped, Sawed		19.5			
C-15	Tacked, Compacted, Overlapped, Sawed		20.1			
C-16	Not tacked, Compacted, Pinched, Wheel Cut		18.7			
C-17	Not tacked, Compacted, Bumped, Wheel Cut	19.4				
	Cold Joints - Maryland - continued					
C-18	Not tacked, Compacted, Overlapped, Wheel Cut		18.4			
C-19	Not tacked, Pinched, Sawed, I-R Heated		2.4			
C-20	Not tacked, Bumped, Sawed, I-R Heated	17.1				
C-21	Not tacked, Overlapped, Sawed, I-R Heated		11.1			
C-22	Not tacked, Pinched, Wheel Cut, I-R Heated		4.6			
C-23	Not tacked, Bumped, Wheel Cut, I-R Heated	22.9				
C-24	Not tacked, Overlapped, Wheel Cut, I-R Heated		16.8			
C-25	Tacked, Compacted, Bumped, Wheel Cut		13.1			
C-26	Tacked, Compacted, Overlapped, Wheel Cut		17.9			
C-27	Tacked, Compacted, Pinched, Wheel Cut		15.1			
C-28	Lane Sample for Comparison					38.9
C-29	Lane Sample for Comparison					40.4
C-30	Lane Sample for Comparison					39.2
C-31	Lane Sample for Comparison					23.9
C-32	Lane Sample for Comparison					39.0
C-33	Lane Sample for Comparison					36.9
	Cold Joints - North Carolina					
D-1	Tacked, Overlapped		15.0			
D-2	Not tacked, Overlapped, Bumped	29.0				
D-3	Not tacked, Overlapped	7.0				
D-4	Not tacked, Bumped		4.5			
D-5	Not tacked, Overlapped				6.5	
D-6	Not tacked, Overlapped, Bumped				3.0	
D-7	Not tacked,				6.0	
D-8	Tacked, Overlapped, Bumped	12.0				
D-9	Tacked, Overlapped	19.0				
D-11	Tacked, Overlapped	8.1				
D-12	Tacked, Bumped, Pinched	12.0				
D-13	Tacked, Pinched		7.0			
D-14	Tacked, Bumped, Pinched	8.0				
D-15	Not tacked, Overlapped	27.5				
D-16	Not tacked, Overlapped, I-R Heated	25.0				

temperature (70 to 75 F) during storage, and ambient temperature during testing was in the same range.

The location of the first crack and the load applied at its appearance were determined. In many cases, the samples failed at locations other than at the joint. Loading was continued to maximum, which was the value used in all data comparisons. Sample measurements, to the nearest $\frac{1}{16}$ in., were used in computing areas used in reducing total load to pounds per square inch (Table 3).

TEST RESULTS

Density Gradient

An unanticipated finding of these studies is the presence of a severe density gradient across the joint in cold-joint construction and in certain types of semi-hot joint construction (Fig. 5). Also, the area of low density is in the edge of the lane placed first, whereas practically all the special joint construction procedures, such as bumping or pinching, are concerned with attempts to get a high density at the joint in the lane placed subsequently. The extent of the low and high density areas was not determined in these studies and the density gradients shown in Figure 5 are based on judgment.

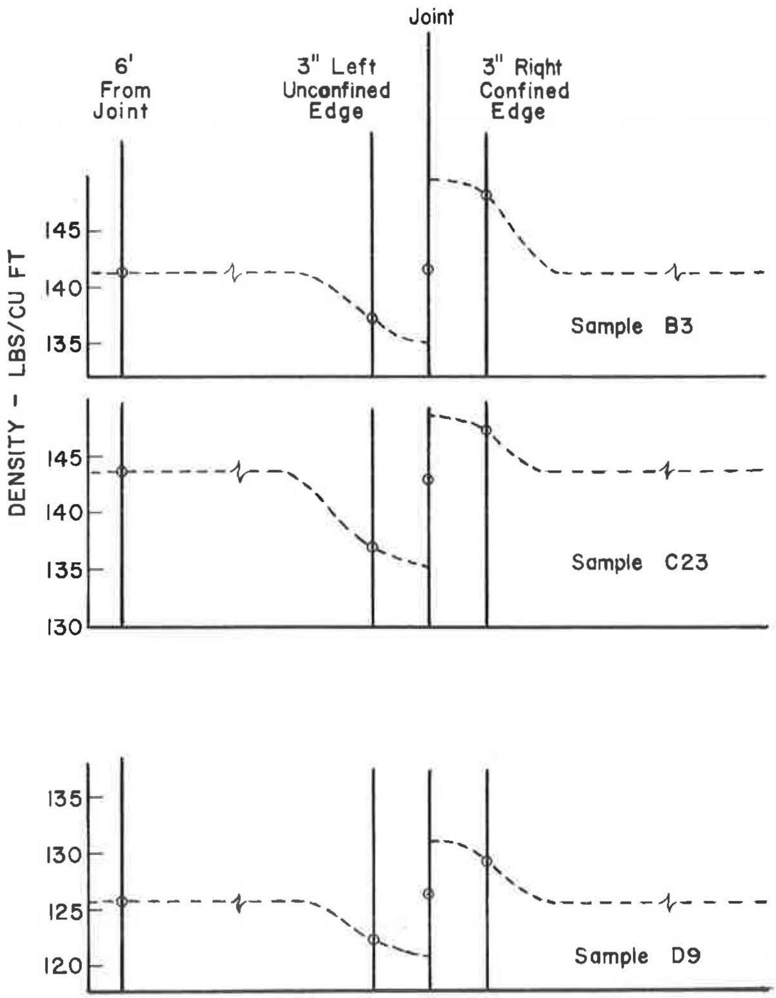


Figure 5. Typical density gradients across joint.

TABLE 4

AVERAGE DENSITIES OF SEMI-HOT JOINTS

Position	Density[a]							
	Overlapped		Pinched		Bumped		Uncompacted	
	Pcf	%	Pcf	%	Pcf	%	Pcf	%
3 in. left	144.2	102.1	139.6	99.1	137.9	97.6	137.5	97.4
Joint	141.8	100.4	143.1	101.4	143.2	101.4	136.5	99.7
3 in. right	145.9	103.3	146.7	103.9	147.9	104.7	147.1	104.2

[a]Percentages based on average lane density of 141.2 pcf.

This unanticipated low density in the unconfined edge may well be the cause of the inability to compact the edge of the first lane properly with present equipment. This low density, as brought out in this analysis, is not solved by tacking or infrared heating. Bumping and pinching the joint on the opposite side does not correct the condition and may serve to accentuate the problem in that it creates a hard spot from the material crowded in at this point. From a theoretical standpoint, a uniform gradient at the same density level as the rest of the pavement is desirable. Areas of low density are subject to more rapid deterioration from oxidation and may even permit entrance of water. Areas of high density may cause a stress concentration during thermal expansion and contraction and induce cracking. Because the low density appears to be the more severe problem, the analyses of the density data in this report are concerned primarily with the values measured 3 in. left of the joint in the unconfined edge.

Hot Joints

Observations and density tests of the hot joints indicated that there was virtually no longitudinal joint as such, and the lanes were in essence a single entity. Average densities at 3 in. left, 3 in. right, and at the joint were 143.5, 143.6, and 142.7 pcf or, in terms of percent considering 142.6 pcf the average of the lane samples, 100.5, 100.6, and 99.9, respectively.

Tensile test results of the hot joint were higher than those from the lane sample (Table 3); however, the density of the lane sample was relatively low so this comparison should not be given much weight.

Semi-hot Joints

Semi-hot joints, as might be expected, represent a compromise between hot and cold joints. Table 4 summarizes the densities measured at the semi-hot joints. The use of a tack coat was not considered in the measurements because it should have very little effect on density. It will be noted, that the overlapped joint showed significantly higher densities 3 in. left of the joint than the other methods. Densities 3 in. right of the joint were much greater than the average of the lane samples in all cases. Comparison of the tests where the sample failed at the joint (Table 3) indicates that the tensile strength of untacked joints was of the order of or higher than samples with tack. Also, of the six untacked samples tested, three failed at locations away from the joint, whereas of the four tacked samples tested, three failed at the joint. It is apparent that the tack provided no improvement in the tensile strength; however, it may be effective in improving resistance to infiltrating water. This feature was not studied.

Maryland Densities. —An inspection of the density values 3 in. left of the joint (Table 2) shows those of Samples C8, C9, and C27 were much less than the other values for no apparent reason, and these have not been used. Also, the primary variable affecting the density 3 in. left of the joint was whether or not the joint was cut back. Therefore,

in these analyses, all values for cut joints are compared to averages for uncut joints to show the effect of a specific variable.

Infrared heating of the joint had a small effect on the density 3 in. left of the joint when the joint was cut back (139.1 pcf with heating vs 138.1 pcf without) but showed no effect where the joint was not cut back (137.1 pcf with heating vs 137.5 pcf without).

At 3 in. left of the joint sawing produced very slightly higher densities (0.5 to 0.8 pcf) than wheel cutting. There was no consistant variation in the density for overlapped, bumped, or pinched joints.

Average densities of all cut and uncut joints are compared in Table 5. Cutting back the joint increased density at 3 in. left of joint about 2 pcf. The lane density in these tests is about 4 to 5 percent less than that found in the tests on hot and semi-hot joints in Maryland and on cold joints in North Carolina. No explanation can be given for this, because the spread is about 5 percent between left and right in all cases.

TABLE 5

AVERAGE DENSITIES OF CUT AND UNCUT JOINTS

Position	Density[a] Cut Back Pcf	Cut Back %	Not Cut Back Pcf	Not Cut Back %
3 in. left	139.2	96.8	137.3	95.5
Joint	139.6	97.1	137.1	95.3
3 in. right	144.9	100.8	144.0	100.1

[a]Percentages based on average lane density of 143.8 pcf.

Maryland Tension Tests.—Figure 6 is a plot of tensile strength vs density. Samples C-19 and C-22 failed at a crack present in the sample before the test was started and these values are not used. Also, three samples were not used because the density values seemed too low. Results of tests that failed at the joint are shown in large symbols. The points that plot well above the curve, indicating lower tensile strengths than nonjointed material of the same density, are all samples from joints cut back with either the wheel or the saw; however, some samples from joints that were cut back show strengths equal to nonjointed material. Cutting back the joint may, but not necessarily will, produce a low tensile strength. Figure 6 indicates that the tack coat (solid symbols) apparently increased the tensile strength for sawed joints but not for wheel-cut joints. Of samples that failed at the joint, nine were tacked and five were not; of those that failed away from the joint, four were tacked and seven were not. This indicates that the tack was not effective in increasing tensile strength.

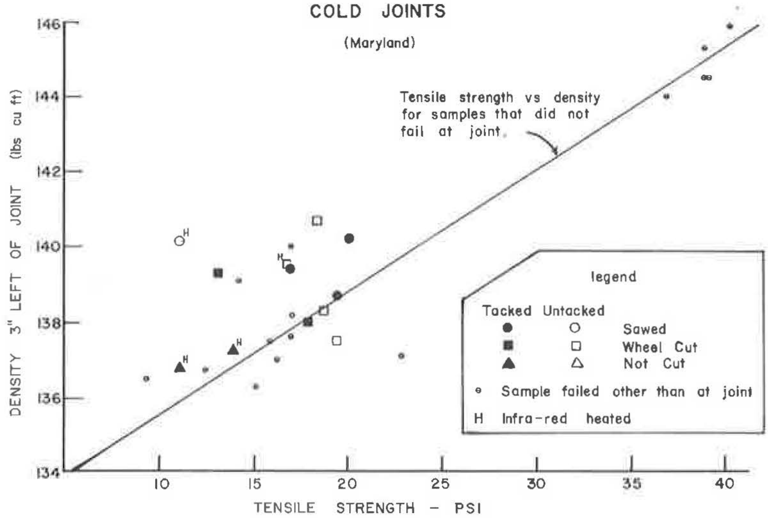


Figure 6.

TABLE 6

AVERAGE DENSITIES OF NORTH CAROLINA SAMPLES

Treatment	Density[a]					
	3 In. Left		Joint		3 In. Right	
	Pcf	%	Pcf	%	Pcf	%
Overlapped and I-R heated	126.5	100.6	128.0	101.8	131.5	104.6
Overlapped or bumped	125.0	99.4	126.2	100.2	130.6	103.8
Bumped plus overlapped or pinched	122.8	97.6	125.7	99.9	129.5	103.0

[a]Percentages based on average lane density of 125.8 pcf.

The data plotted on Figure 6 do not indicate that infrared heating was effective in increasing the tensile strength of cut joints.

North Carolina Densities. —Average densities from tacked and untacked cases are given in Table 6. Infrared heating increased the density 3 in. left of the joint slightly. Bumping and overlapping gave essentially equal results, but combinations of bumping with either pinching or overlapping gave the lowest densities.

North Carolina Tension Tests. —Figure 7 is a plot of tensile strength vs density. The two cases plotted where the tests failed at the joint show tensile strengths a little less than those of samples not failing at the joint. One of these joints was tacked; the other was not. Other evidence that the tack coat was not particularly effective in increasing tensile strength is that two of the three samples that failed at the joint were tacked, whereas seven of the thirteen samples that failed away from the joint were not tacked. Only one heated joint was tested (D-16). It did not fail at the joint, but the tensile strength was no higher than a companion (D-15) unheated joint.

DISCUSSION

Because bituminous surface mixture has been observed to move laterally under breakdown rolling, the resulting low density at the edge of the lane appears logical. How far this low-density area extends from the joint and what can be done to correct the weakness remain questionable.

It is not essential to know the extent of the low-density area if truly confined rolling can be accomplished. For example, if forms are used to confine the initial lane, the need for further defining the problem area is unnecessary. However, an approach

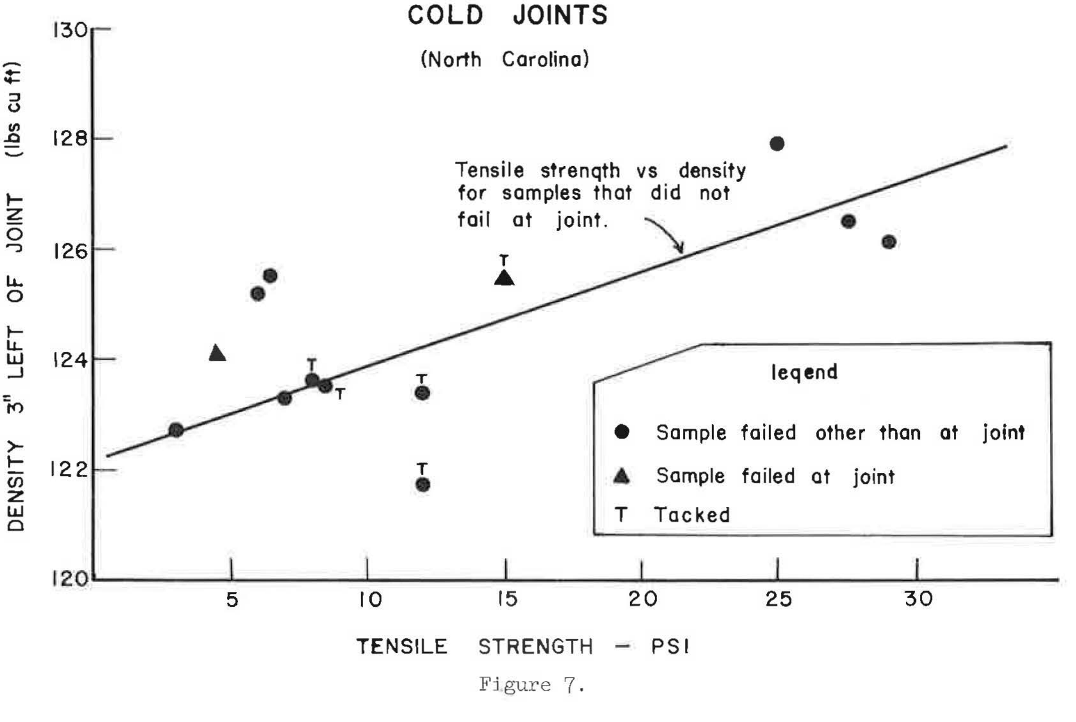


Figure 7.

successfully accomplishing the purpose might be either impractical or economically unsound. Defining the extent of the low density area would make possible a number of alternate approaches to a more reasonable solution.

One further point should be made in this regard. If the exact location of the joint had not been carefully defined before paving the second lane in these studies, many joints would have been assumed to be located 2 to 3 in. to the cold side of the true location. This apparent shift is generally caused by the normal overlap of second-lane material onto the first. Material is pushed back off the cold pavement, but the evidence of this overlap remains. Several times, workmen insisted that the reference lines were incorrect when samples were being cut. Subsequent visits to the test areas showed that the incorrect evidence of joint location remained. Therefore, much of the so-called joint failure apparently centered over the joint may in fact be entirely in the uncompacted area in the unconfined lane.

This, then, is the problem. Rolling a bituminous surface mix in a plastic state without edge confinement cannot produce the density designed or required. When the resulting pavement cools before the adjoining lane is placed, an inherent weakness is left in the area extending from the joint for an unknown distance into the first lane paved. Eventually, some form of confinement, edge compaction, infrared heating or a combination of these may provide a workable solution.

FINDINGS

This investigation found that a low density zone at the edge of the initial lane and a high density zone at the edge of the subsequently laid lane exist that are not present in hot joints made with pavers operating in echelon. In addition, the results show that:

1. Overlapped rolling produced the highest densities in the initial lane in semi-hot joint construction;
2. There was no clear-cut superiority to any of the procedures used in cold-joint construction from the standpoint of density in the initial lane except that combinations of bumping and pinching and bumping and overlapping produced the lowest density;
3. Cutting back the joint improved density in the initial lane slightly but caused low tensile strengths;
4. Infrared heating improved density slightly in the initial lane but did not improve tensile strength;
5. Tack on the edge of the joint did not improve tensile strength.

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