Electrically Conductive Asphalt for Control of Snow and Ice Accumulation

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An asphaltic concrete made electrically conductive by the addition of graphite was designed and tested in small test plots over two winter seasons. Power dissipation per unit surface area, P/A_S, in watts/ft², is $P/A_S = \left(\frac{E}{\ell}\right)^2 \frac{t}{\rho}$, where E = applied potential difference, volts; ℓ = conducting path length; t = thickness of conducting sheet, in.; and ρ = resistivity of material, ohm-in.

From the design requirements of 20 watts/ft², ½-in. thickness, 30-volt potential drop between electrodes spaced 5 ft apart, the necessary resistivity was calculated to be 1 ohm-in. Laboratory studies to obtain this value were made, first using simulated asphaltic concrete (paraffin as a binder) and then asphalt-graphite-aggregate briquettes covering a wide range of mixtures. These studies led to the choice of a 25 percent graphite level, and six test sections were constructed at USA CRREL using this mix and three thicknesses and sizes of electrodes. Actual resistivities were 7 to 12 times design value. Mixing, placement and control are critical in achieving satisfactory electrical properties. The test sections performed satisfactorily over a two-winter observation period. The sections were not trafficked and measurements of resistivity showed increases of 21 to 83 percent over an 18-month period. Safety considerations would probably make necessary an overlay, since a steel form placed on one test section and loaded by standing on it resulted in a 40 percent current increase. Cost of a conductive asphalt with electrodes would be competitive with other methods of heating pavement surfaces.

•PRESENT practical methods of control of snow and ice accumulation on paved surfaces can be classified as chemical, mechanical, and thermal. Melting of frozen precipitation by heat can be accomplished by direct application of thermal energy from an exposed flame or an electrically energized radiant source, by pipes carrying hot liquid, or by electrical resistance cables buried in the upper portion of the pavement. The buried electrical cable method has much to recommend it, for it enables the heat to be applied more efficiently to the snow or ice than the other methods. However, there are drawbacks to the use of buried heating cables: either the spacing between the cables must be very small, or temperature of the cables must be very high, to obtain adequate heat input to melt snow or ice in the areas between them. Furthermore, cables must be buried relatively deep in the pavement to obtain the optimum distribution of heat for a given electrical input and cable size—British practice is to bury cables 2 in. below the top surface, with a spacing of 6 in. (1). This requires a major construction job for placement of the cables as well as the undesirable task of breaking the pavement surface in old construction.

A method of applying thermal energy close to the surface, and evenly, is clearly desirable. The 3-P thermo-pavement system developed in Switzerland—now called

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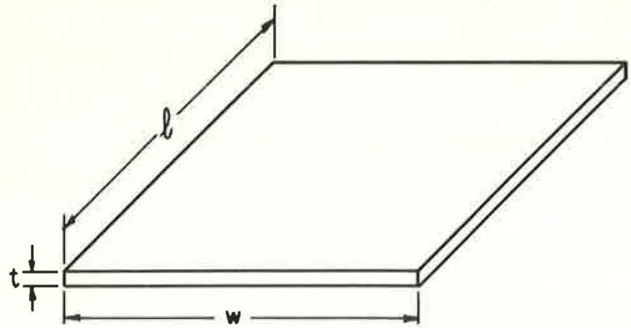

Figure 1. Geometry of the conductive sheet.

Calorway and used in Austria (2)—attempted this; but this system, which required laying insulated heating cables in a prefabricated plastic grid, then covering the whole with a sand-asphalt wear course, is costly in both labor and materials and can be damaged too easily. The latter factor is critical since this system operates at 1000-V potential. Any cable heating system is subject to damage which is both difficult and costly to repair. These considerations led to the investigation of electrically conductive asphalt as a means of heating the pavement surface.

PRINCIPLES

Power dissipation in an isotropic conductive sheet (Fig. 1) is described in the following paragraphs.

Power is consumed when current flows through a purely resistive load under an applied potential according to the relation

$$P = EI = \frac{E^2}{R} \tag{1}$$

where

P = power dissipated, W;
E = applied potential difference, V;
I = current, amp; and
R = resistance, ohm.

Materials exhibit a resistance directly proportional to the length of the conducting path and inversely proportional to the cross-sectional area of the conducting element, A_c, or

$$R = \rho\frac{\ell}{A_c} = \frac{\rho\ell}{tw} \tag{2}$$

where

R = resistance, ohm;
ρ = proportionality constant, resistivity, ohm-in.;
ℓ = conducting path length, ft;
t = thickness of conducting sheet, in.; and
w = width of conducting sheet, ft.

Substituting Eq. 2 in Eq. 1 gives

$$P = E^2\frac{tw}{\rho\ell} \tag{3}$$

Power dissipation per unit surface area, A_s, is

$$P/A_s = \frac{E^2}{w\ell} \cdot \frac{tw}{\rho\ell} = \left(\frac{E}{\ell}\right)^2 \frac{t}{\rho} \tag{4}$$

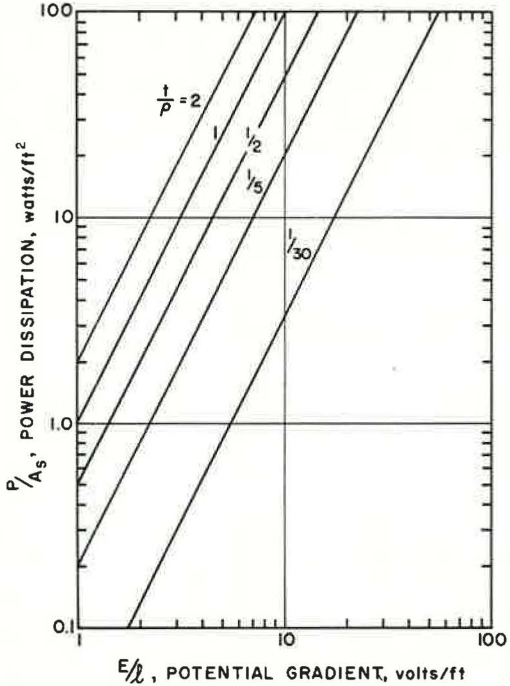

Figure 2. Power dissipation vs potential gradient.

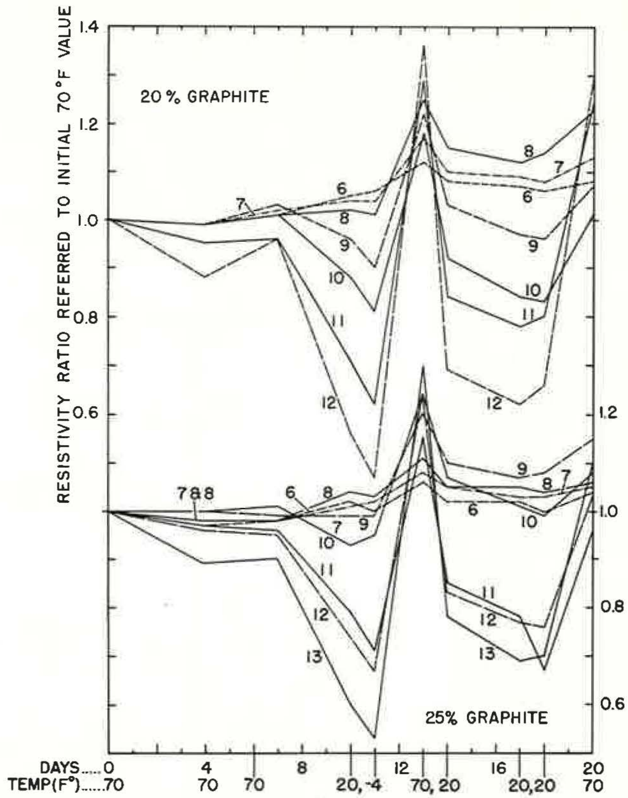

Figure 3. Change in resistivity with temperature for 2 levels of graphite and 7 levels of asphalt (parameter is asphalt content, %).

Figure 4. Test area following a 2⅛-in. snowfall (December 13, 1965); 1 #2 test section is in) foreground, and reading to right are the 1 #6, 1 #2, 1 #6, #6, (snow covered) and # 10 sections.

TABLE 1

VOLUME RESISTIVITIES OF ASPHALTIC-CONCRETE INGREDIENTS

Material	Resistivity, ρ		Source
	Ohm-Cm	Ohm-In.	
Asphalt	10^{14}	$\sim 4 \times 10^{13}$	(3)
Graphite (pure)	0.0008-0.0013	0.0003-0.0005	(4)
Limestone	10^{4}-10^{5}	4×10^{3}-4×10^{4}	(5)
Granite	10^{7}-10^{9}	4×10^{6}-4×10^{8}	(5)
Sand	10^{5}-10^{6}	4×10^{4}-4×10^{5}	(5)

TABLE 2
TEST PANEL CHARACTERISTICS

No.	Panel Designation[a]	Resistance Between Outer Conductors (ohm)			
		10/6/65	10/27/65	12/21/66	4/21/67
1	½ # 10	39.6	47.3	54	82
2	½ # 6	116	115	168	141
3	1 # 6	33.0	45.7	79	84
4	1 # 2	26.5	46.6	47	69
5	1½ # 6	17.5	23.5	38	43
6	1½ # 2	12.5	18.0	32	28

[a]First number is the asphalt thickness; second number is the gage of the stranded copper cable used as conductor.

TABLE 3
WEATHER

Date	Temperature	Winds	Sky
10/6/65	48 F	12 kt	Sunny
10/27/65	43 F	Calm	Cloudy
12/21/66	28 F		
4/21/67	46 F	Slight breeze	Clear

This has the form of $y = ax^2$, a parabola, and is most conveniently graphed on log-log scales (Fig. 2); the ratio t/ρ, conductance is the parameter.

DESIGN FACTORS

Maximum power dissipation required for test purposes was established as 20 W/ft² (from work carried out in England and the United States). Maximum potential drop should preferably not exceed 30 V between electrodes for safety reasons.

Desired thickness of conducting material is ½ in., chosen to require the minimum amount of material consistent with ease of placement and minimum disturbance of the electrical field if superficial gouging by traffic action occurs. An approximately 5-ft spacing between electrodes is desired, thereby setting a potential gradient of 6 V/ft. The power dissipation and potential gradient requirements establish the t/ρ ratio as

CONDUCTIVE

Date	New Snow (in.)	Wind Speed (mph)	Air Temp. (°F)	½ # 10			½ # 6		
				P_{tot} (watts)	P/ft² (watts/ft²)	Clear (%)	P_{tot} (watts)	P/ft² (watts/ft²)	Clear (%)
12/20/65	⅞	Calm	7	448	12.5	100	127	3.5	0
1/3/66	¼	Calm	26	505	14.0	Thin covering[a]			
1/7/66	¼	8 mph	30	572	16	100			
1/24/66	16½	8 mph	25	500	13.9	Ctr 100			
12/6/66	½	Calm	30	360[b]	20	50			
12/14/66	2	Calm	27-32	720	20	100			
12/25/66	9½	Calm	27-32	600	17	90	130	3.6	0
12/29/66	2	Calm	23	600	17				
1/13/67	2	Calm	27	600	17	100	240	6.7	95
1/30/67	2-3	15-25 mph	17	600	17	25	180	5.0	10
2/2/67	3-4	Calm	34	600	17	100	180	5.0	Slush
2/8/67	1-2	Calm	16	600	17	50	180	5.0	0
2/21/67	5	Calm	23-28	600	17	100	180	5.0	50
2/24/67	10-12	10-15 mph	20	600	17	0	180	5.0	0
3/6/67	2	Calm	29	600	17	100	180	5.0	0
3/8/67			20-30	600	17	80	180	5.0	0
3/16/67	4	5 mph	26	600	17	100	180	5.0	0 (ice)

[a]Light snow fell during night of Jan. 2-3. Panel 1½ # 6, unheated, did not accumulate; snow adhered to all heated panels, then froze when tem dropped to 20-22 F.
[b]Only half of panel was energized.

approximately 1/2 (Fig. 2). From this, it is seen that a material having a resistivity of $\rho = 2t = 1$ ohm-in. is required. This was the goal in the material tests that were made.

LABORATORY TESTS

Materials

A search of the literature revealed no information on the electrical properties of asphaltic concrete pertinent to this investigation. Therefore, experiments were designed to determine the influence of a conductive additive such as graphite. Published values of volume resistivities of asphaltic-concrete ingredients were found and are given in Table 1. Replacing a portion of the mineral aggregate with a material of higher conductivity such as graphite would offer an approach to obtaining an average resistivity of approximately 1 ohm-in. Just how much aggregate must be replaced is difficult to compute, since neither the particle size distribution of graphite after mixing nor the extent of the carbon-to-carbon chains that may be formed by compaction are known. Sample briquettes were therefore prepared and resistances measured with either a Rubicon Wheatstone bridge or a General Radio type 650-A impedance bridge.

Exploratory tests were made using paraffin as a binder for graphite, graphite-aggregate, and graphite-aggregate-aluminum particle mixes. These were followed by the preparation by the Soils Laboratory, U. S. Army Corps of Engineers, New England, of standard Marshall briquettes for combined stability, flow, and resistivity measurements for a range of conductive asphalt compositions (6). Resistivity was determined by attaching wire electrodes to the briquette faces by brushing on silver conductive paint (Du Pont type 4817) and measuring the resistance on the bridge. A two-level factorial design experiment with three factors (asphalt, graphite, and aluminum) led to the rejection of aluminum as of significant value.

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		1 # 2			1½ # 6			1½ # 2		
²)	Clear (%)	P_{tot} (watts)	P/ft² (watts/ft²)	Clear (%)	P_{tot} (watts)	P/ft² (watts/ft²)	Clear (%)	P_{tot} (watts)	P/ft² (watts/ft²)	Clear (%)
	100	352	9.8	80	565	15.7	90	672	18.7	100
	Thin covering[a]	287	11.7	Thin covering[a]						
	100	316	8.8	100						
	Ctr 100	280	7.8	8 cm deep						
	100	595	16.5	100						
	100	595	16.5	100						
	95	510	14	90						
	100	650	18	100	560	16	100	760	21	100
	20	600	17	95	560	16	50	800	22	40
	100	600	17	100	560	16	100	800	22	100
	50	600	17	95	560	16	100	800	22	95
	100	600	17	100	560	16	100	800	22	100
	0	600	17	0	560	16	0	800	22	10
	100	600	17	100	560	16	100	800	22	100
	100	600	17	100	560	16	100	800	22	100

TABLE 5
TEST PROPERTIES AND RANGES REQUIRED

Test Property	Criteria (roads)	Test Results (at 10.0% A.C.)	Required Range
Stability, lb	500+	1260	1100+
Flow, 0.01 in.	20-	12	10-14
Voids total mix, %	3-5	4.1	3-5
Voids filled with asphalt, %	75-85	83.7	75-85
Density, pcf	—	133.6	—[a]

[a]The density of pavement placed is required to be greater than 98 percent of the density obtained on field-molded specimens of the same mixture using 50 blows per side of the Marshall hammer.

In a new set of briquettes prepared by the Soils Laboratory the asphalt content was increased to improve workability, and the graphite level increased to meet the electrical requirements. The effect of temperature cycling on the resistivity for two levels of graphite (20 and 25 percent) is given in Figure 3. This is presented as the ratio of the resistivity for the data shown on the abscissa to the initial resistivity (measured at 70 F). Increasing the asphalt decreased the deviation of resistivity from the norm (initial 70 F measurement) for both room and low temperatures. The limited data also suggest that the deviation from the initial value decreases with the number of cycles.

FIELD TESTS

A 6 by 8-ft outdoor test section constructed on an existing asphalt parking area of USA CRREL's Hanover laboratory in November 1964 was only partially successful. The mix failed to meet design objectives because of the contractor's unfamiliarity with such an unusual mix; he was forced to add considerably more asphalt than the design called for in order to obtain workability and eliminate lumps caused by adding cold graphite to the mix. Placement was marred by poor thickness control and rapid setting of the mix. Nonetheless, the test section was kept free of ice and snow during the winter, although a high voltage was required for the purpose.

An additional set of outdoor conductive asphalt test sections was constructed in the parking area of USA CRREL in October 1965 and measurements and observations were made over two winter seasons (Fig. 4) 1965-1966 and 1966-1967. These additional sections were designed to investigate the influence of thickness, diameter of embedded conductor, power level, long-term aging characterisitics, durability, and safety. A new mix was designed because of the change in suppliers of the graphite: 10 percent asphalt and 25 percent graphite were used.

Six 6 by 6-ft holes were cut in the existing asphalt parking lot at USA CRREL and backfilled with sand and standard hot mix to give unfilled depths of ½, 1, and 1½-in. (two of each). The graphite balling which occurred during the preparation of the first mix was controlled by dimping warm, preheated bagged graphite through a port in the hopper cover directly into the pugmill after the aggregates had been batched. An insignificant amount of graphite was lost from each bag by leakage.

The test sections were connected to center-tap transformers which were in turn connected to autotransformers for voltage control. The connections were varied during the early part of each season to obtain a spread in power densities (Table 2 and 3).

The resistance of all test sections increased between the time of placement and the final measurement at the end of the second winter season. In some cases, however, the resistance dropped between the middle of the first winter and the end of the second winter, suggesting that the change in resistance may not only be a chemical change (degradation of the asphalt) but may also be a physical change such as voids forming within the mass. This would be particularly critical around the conductors. Since the test sections were not trafficked at any time, there was no compaction other than that at construction and that required to repair the loosened conductors at the beginning of the second season.

Observations of the test sections during periods of precipitation, and their power inputs, are given in Table 4.

Table 5 gives the required Marshall properties of an asphalt pavement and the results that were achieved with the conductive asphalt mix used in the six test sections.

DISCUSSION

Safety

Accidents in which metal conductors fall across the conductive asphalt, or perhaps penetrate the surface, are likely to occur. This aspect of safety was the basis for the design criterion of a 6 V/ft potential gradient. Rudimentary tests to investigate the potential hazard were made on the $1\frac{1}{2}$ #2 panel on a dry, warm day. A steel channel across the panel (energized at 80 V across the outer conductors) caused little change in current flow. However, loading the panel with about 325 lb (two people standing on it, one on each end) caused a 30 percent jump in current. Water alone across the panel resulted in an imperceptible change in current. The current increased less than 10 percent when the unloaded steel channel was placed on the wet panel. A final test was performed by grooving the asphalt about $\frac{1}{2}$ in. deep for a length of 8 in. and placing the steel channel across the dry panel and in the groove. When the channel was loaded by the two people stepping on the ends, the current increase was greater than 40 percent. Thus, the safety hazard is great enough to require a protective surface coating; no studies of such a coating have been undertaken.

Cost

Graphite substitutes for a portion of the sand; therefore, its cost is almost entirely added to the cost of the asphalt mix. The type of graphite used in all the mixes tested costs 7 to 8¢/lb, depending on quantity, FOB plant. For a quick computation, a figure of \$200/ton delivered is used. The unit weight of a 10 percent asphalt, 25 percent graphite mix is about 134 lb/ft^3. A 1-ton batch of this mix which contains 450 lb of graphite makes a $1\frac{1}{2}$-in. thick overlay over an area of 120 ft^2 at a cost for graphite of $37\frac{1}{2}$¢/ft^2. In the test arrangement, 0.5 linear feet of cable was used per square foot of heated surface. For No. 10 stranded cable this would involve a cost of about 5¢/ft^2. Thus, the added cost for materials for conductive asphalt pavements totals approximately 45¢/ft^2. Placement costs may be somewhat higher than those for a conventional pavement because of the greater mix and thickness control necessary. However, the total cost exclusive of the electrical distribution system would probably be close to the \$1/ft^2 cost of conventional resistance cable or mesh heating installations (7).

ACKNOWLEDGMENTS

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