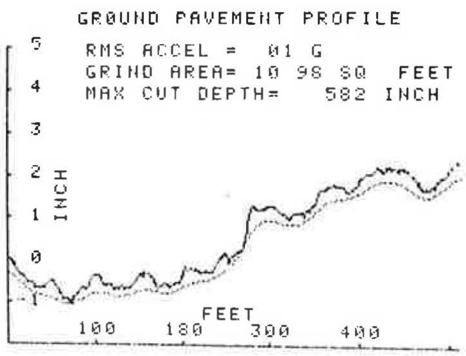

Figure 10. Computed ground pavement profile.

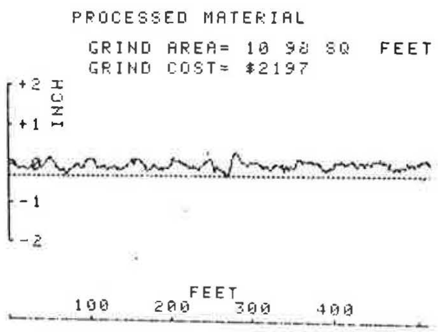

Figure 11. Pavement grind depth-of-cut.

data processing center through a conventional phone line interface.

CONCLUSIONS

The capabilities of the inertial profilometer have continued to improve since its early development at GMR in the 1960s. Its continued development has resulted from advancements in instrumentation, digital signal processing, and the expanded demands of the user community. These advancements have led to a high-quality, cost-effective tool for the evaluation of pavement condition, which has capabilities far beyond its original pavement profile measuring task. The profilometer system's ability to collect, store, retrieve, and process pavement management field data gives it the potential to be an important element in the total pavement management process.

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Publication of this paper sponsored by Committee on Pavement Condition Evaluation.

Prediction and Significance of Wet Skid Resistance of Pavement Marking Materials

D.A. ANDERSON, J.J. HENRY, AND G.F. HAYHOE

A data base of full-scale locked-wheel skid resistance is presented for typical marking materials, including traffic paints of various formulations, hot spray and extruded thermoplastics, cold preformed plastics, temporary tapes, and some two-part systems. A variety of pavement surface types, including dense- and open-graded asphalt and portland cement concrete, are used in the study. British pendulum numbers and macrotexture profile data are presented for field applications and for laboratory samples of marking materials. Equations are developed for predicting skid resistance from these data. The effects of glass beads, weathering, and polishing are examined in laboratory and field experiments. In all cases, the skid resistance of the marking materials is less than that of the pavement to which they are applied. From the results of a simulation study, a description is given of the effects of differential pavement friction on the handling and stability of four-wheeled vehicles and single-track vehicles. A tentative procedure for setting minimum acceptable levels of marking material skid resistance for four-wheeled vehicle operation is developed from the simulation results. A procedure for setting minimum levels of skid resistance for single-track vehicle operation could not be established. An alternative approach to the problem is suggested.

Little is known about the high-speed wet skid resistance of pavement marking materials. Michigan (1) measured the skid resistance of paints and plastics installed on concrete pavements. Skid resistance at 64 km/h (SN_{64}) ranged from 4 to 37 and British pendulum numbers (BPN) ranged from 14 to 31. These values are cause for concern, particularly during

Table 1. Materials included in research program.

Material[a]	Code	No. of Formulations Studied
Conventional Alkyd paint	AC	2
Conventional chlorinated rubber paint	CC	2
Alkyd quick-dry paint	AQ	2
Chlorinated rubber quick-dry paint	CQ	2
Alkyd paint with premixed glass beads	AP	2
Chlorinated rubber paint with premixed glass beads	CP	2
Hot extruded thermoplastic	HE	5
Hot sprayed thermoplastic	HS	3
Cold applied plastic	CA	10
Temporary tapes	TT	5
Two-part epoxy and polyesters	TP	4

[a] The materials were further coded according to the following scheme (e.g., AC1WU): AC = conventional alkyd; 1, . . . n = formulation number; W = white (Y = yellow); U = unbeaded (B = beaded).

lane changing maneuvers and for two-wheeled vehicles. Whereas these numbers are cause for concern, there is no analytical technique or field test procedure for determining whether or not they constitute a safety problem.

One approach for assessing the significance of the skid resistance of marking materials would be to study accident data, as has been attempted for pavements (2). Unfortunately, definitive accident data are not available and, in the absence of these data, it is necessary to use analytical and simulation techniques to evaluate the effect of marking material skid resistance on vehicle performance.

This paper summarizes an extensive research study that was conducted on the skid resistance of pavement-marking materials. Three main points are addressed: (a) development of a data base, (b) prediction of field skid numbers from laboratory tests, and (c) results of computer simulation analysis on the significance of differential skid resistance.

TESTING PROGRAM

The various marking materials used in this study are summarized in Table 1. Five substrates were selected for the laboratory testing: smooth metal, fine sand asphalt, open-graded friction course, dense-graded asphalt, and broomed portland cement concrete (PCC). Individual 100x150 mm panels were made for each of the surfaces and the marking materials were applied with field application equipment at the same time the material was applied to the field test surfaces.

The marking materials were also applied to a number of pavement surfaces in the field, including dense-graded asphalt, open-graded asphalt, PCC, and a fine sand asphalt. The field sites included public roads with traffic as well as sites at the skid test facility of the Pennsylvania transportation facility, where there was no traffic. In all cases, except for the two-part polyester and epoxy materials, conventional application equipment was used so that the materials would be representative of full-scale field applications. Full details of the application procedures and the test surfaces are given elsewhere (3).

Laboratory Testing

The laboratory test procedures that were selected were designed to condition the samples in order to simulate traffic wear and environmental exposure. Measurement techniques included microtexture and macrotexture measurements and BPN.

The Pennsylvania State reciprocating pavement polisher was used to simulate field polishing. A five-step polishing sequence that used five grit sizes (105-, 74-, 30-, 15-, and 5-μm grit) was required to obtain terminal polishing with unmarked pavement samples. For the marking materials, a single polishing sequence with 1000 cycles and 30 μm grit produced terminal polishing (3). The polishing mechanism was different for the beaded and the unbeaded surfaces. There was no appreciable wear of the beads, even after 1000 polishing cycles. The polishing sequence merely removed paint overspray from the surfaces of the beads, which accounted for the decrease in BPN values for the beaded surfaces after polishing. On the other hand, the behavior of the unbeaded surfaces was erratic--the BPN of some materials increased during polishing whereas others decreased. In general, the increases were associated with very smooth, glazed surfaces such as the epoxies of unfilled paints. Decreases were associated with rippled or rough surfaces or with premixed materials where the polishing removed surface asperities.

Based on the test results, mechanical conditioning of the panels is necessary before BPN tests are conducted. Wear in the traditional sense that occurs with aggregate does not occur with marking materials. For beaded surfaces it is necessary to remove overspray so that the beads are exposed to the foot of the BPN pendulum. If the overspray is not removed, the reported BPN values will be in error on the high side. For the smooth, glazed surfaces polishing tends to increase the BPN value.

The foot of the pendulum can also condition the surfaces. Approximately seven swings of the pendulum are required to stabilize the readings. If ASTM E303 is adopted for use with marking materials, it will be necessary to change tne test procedures so that, for example, the last four of seven readings are reported rather than simply deleting the first reading as is now specified (3).

It is imperative that laboratory samples be prepared in the same manner and with the same equipment as used in the field. The sprayed-on beads produced BPN values 14 points higher than did the dropped-on beads. Similar comments apply to spraying techniques and to materials applied with a doctor bar. The method of application can have a greater effect on the BPN values than will differences in materials.

Beaded and unbeaded panels were exposed in an Atlas Twin Arc Weatherometer. Microtexture and macrotexture values were not significantly different before or after exposure. Decreases in BPN were associated with beaded surfaces and attributed to a loss in overspray on the bead surfaces similar to the losses during polishing. Increases were associated with the unbeaded glazed surfaces. A patina developed on these surfaces but it was removed during polishing, much as it would be lost in the field due to traffic.

Field Test Program

In order to develop a rationale for predicting skid resistance on the basis of laboratory measurements, it was necessary to conduct full-scale skid resistance measurements and conduct the laboratory measurements both in the laboratory and in the field. These data were then used to develop the relation between skid numbers and the parameters measured in the laboratory. Also, monitoring of the field installations over a period of time provided insight into the effect of exposure to traffic and weather conditions.

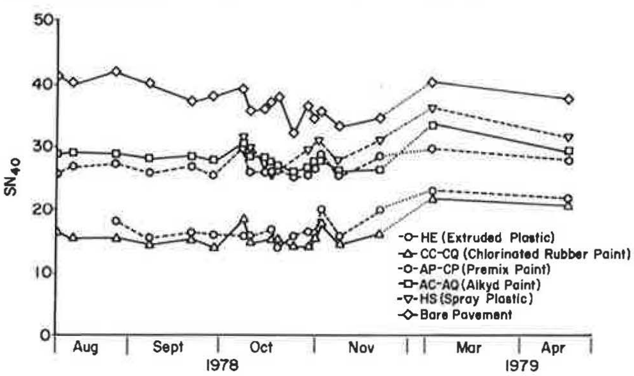
To obtain skid numbers by using the Pennsylvania Transportation Institute (PTI) Mark III pavement friction tester, which conforms to full-scale locked-wheel skid-tester specification in ASTM

Table 2. Field data.

Material[a]	BPN 10-31-78	RMS (mm) 11-9-78	SN_{64} 10-31-78	BPN 4-13-79	SN_{64} 5-14-79	PNG (h/km) 5-14-79
Open-graded asphalt concrete						
Pavement	93.8		48.4		54.3	0.23
AC1WB	74.6	0.691	32.0	66.0	34.0	
AC1WU	61.4	1.709	30.3	49.4	28.7	0.86
CC1WB	71.0	0.688	31.4	63.6	32.0	1.34
CC1WU	47.0	0.691	16.9	54.2	23.0	1.68
AQ1WB	72.2	1.326	36.1	68.8	40.0	
AQ1WU	70.6	0.770	30.0	72.0	35.5	1.46
CQ1WB	72.2	0.541	39.9	68.0	39.0	1.10
CQ1WU	64.0	0.630	24.7	59.6	30.0	1.14
AP1WB	71.8	0.605	37.8	63.6	37.0	
CP1WU	76.0	1.227	37.0	75.0	49.3	1.12
CA3WB	57.2	0.330	31.8	51.4	31.7	1.53
TT1YB	51.2		47.7	57.0	46.5	1.07
TT2YB	66.8	0.538	41.5	67.0	37.0	0.75
TP1WB	59.8	0.297	37.4	36.6	34.0	1.10
Portland Cement Concrete						
Pavement	58.8		75.8		81.7	
AC1WB	51.8	0.104	17.9	50.4	21.0	1.14
AC1WU	49.2	0.084	12.7	49.8	14.0	1.88
CC1WB	51.2	0.089	17.8	46.4	20.5	1.11
CC1WU	48.6	0.198	9.7	35.6	12.3	2.21
AQ1WB	51.8	0.127	31.5	49.6	31.0	0.98
AQ1WU	66.6	0.074	22.2	62.6	21.5	0.81
CQ1WB	61.0	0.112	25.6	55.2	28.7	1.68
CQ1WU	48.6	0.135	12.8	47.0	14.7	1.96
AP1WB	52.2	0.107	28.2	47.6	25.7	1.31
CP1WB	56.2	0.082	29.4	47.4	32.0	1.72

[a]See Table 1 for explanation of code.

Figure 1. Variations in SN_{64} on the dense-graded asphalt public road site.



E274.79, it was necessary to apply the materials to the pavements in strips 0.3x6.5 m. Particular attention was given to apply the materials with equipment that would be representative of full-scale installations. Special equipment, developed by Prismo Universal Corporation for test line applications, that duplicates the performance of full-scale truck-mounted units was used.

Texture measurements, which can be made on laboratory samples, were performed at the field test sites as the materials aged in the presence of traffic and exposure to the elements. BPNs, which serve as a surrogate for microtexture measurements, and macrotexture profile traces reduced to their root mean square (RMS) values were found to be the most suitable methods for quantifying microtexture and macrotexture, respectively. Sandpatch measurements were unsuccessful on the marking materials because the sand did not show up well against the light background of the marking material and did not form distinct circles on the relatively smooth surfaces. Also, the sand became embedded in the softer plastic materials. Microtexture profile tracing equipment was found to be difficult to operate on many of the marking materials due to the high contact pressure developed under its extremely fine stylus. This pressure caused the stylus to dig into the softer marking material. The Pennsylvania State drag tester and the outflow meter were also considered but were rejected because they are designed for field testing and cannot be easily used with laboratory panels.

Table 2 summarizes typical measurements of skid resistance and texture for each material in fall 1978 and spring 1979 for dense-graded asphalt and PCC pavements. Data on other surfaces can be found elsewhere (3). The fall data include BPN, RMS (macrotexture), and SN_{64}, and the spring data include BPN, SN_{64}, and the percentage of normalized gradient of the skid resistance (PNG).

Examination of the data in Figure 1 reveals some general conclusions. The glass spheres (beads) increased the skid resistance of the paints. The paint surfaces retained their low skid resistance over the winter although they exhibited considerable wear and were expected to increase toward the levels of the unpainted pavement surfaces. This may be due to the combined effect of the loss of beads, which lowers the skid resistance, coupled with the loss of binder, which will eventually restore the original skid resistance of the pavement. The skid resistance of thermoplastics was also increased by beads. However, exposure to winter weather had a greater effect in reducing the advantage offered by the beads. In this case the formulations also contained beads so that when the surface beads were lost, both beaded and unbeaded applications benefited from the premixed beads.

It was not anticipated that pigment would have a significant effect on skid resistance. Three pairs of white and yellow paint formulations without beads were applied to the smooth tar-sand slurry surface. Initially there was no significant difference in skid resistance, but the white paints decreased in skid resistance to a greater extent over the winter,

Figure 2. Predictor equations for skid resistance of marking materials.

a. Traffic Paints

Unbeaded 22 applications $\overline{SN}_{64} = 20.7$ $(s = 8.0)$

$SN_{64} = .64\ BPN - 15.6$ $r^2 = .44$

$SN_{64} = .546\ BPN + 6.10\ RMS - 12.82$ $r^2 = .92$

Beaded 41 applications $\overline{SN}_{64} = 26.7$ $(s = 6.8)$

Chlorinated Rubber Base (20 applications) $\overline{SN}_{64} = 25$ $(s = 8)$

$SN_{64} = .725\ BPN - 15.4$ $r^2 = .61$

Alkyd Resin Base (21 applications) $\overline{SN}_{64} = 28.3$ $(s = 5.1)$

$SN_{64} = .356\ BPN + 7.10$ $r^2 = .36$

b. Thermoplastics

Unbeaded 12 applications $\overline{SN}_{64} = 18.7$ $(s = 10.1)$

Hot Extruded (7 applications)

$SN_{64} = .91\ BPN - 35.3$ $r^2 = .48$

$SN_{64} = .817\ BPN + 13.3\ RMS - 33.1$ $r^2 = .50$

Hot Spray (5 applications)

$SN_{64} = 64.4\ RMS + 3.9$ $r^2 = .45$

Beaded 26 applications $\overline{SN}_{64} = 24.7$ $(s = 7.5)$

Hot Extruded (16 applications)

$SN_{64} = .68\ BPN - 15.4$ $r^2 = .50$

$SN_{64} = .623\ BPN + 36.4\ RMS - 18.7$ $r^2 = .66$

Hot Spray (10 applications)

No acceptable correlation found

SN_{64} Hot Spray > SN_{64} Hot Extruded

c. Preformed Plastics 11 applications $\overline{SN}_{64} = 25.2$ $(s = 8.7)$

$SN_{64} = .158\ BPN + 58.4\ RMS + 5.95$ $r^2 = .76$

Note: The macrotexture profile root mean square (RMS) is expressed in mm in all the above expressions.

which indicates a lesser durability of the white paint when subjected to exposure, even in the absence of traffic.

As in the case of pavements, marking materials exhibit seasonal and short-term variations in skid resistance. These variations are shown in Figure 1. The average values of skid resistance (SN_{64}) are plotted for each formulation type on all days when measurements were made. Also evident in Figure 1 is that the chlorinated rubber base paints and the hot extruded thermoplastics have skid resistances about 10 units less than the other materials tested on this site. The relatively low skid resistance of the chlorinated paints persisted even after the coarse aggregate surface had worn through the paint.

Prediction of Skid Resistance from Texture Measurements

It was originally hypothesized that skid resistance of all types of marking materials could be predicted from texture measurements alone by using one set of prediction equations for all materials, including paints, thermoplastics, temporary tape, or preformed cold-applied plastics. However, a preliminary analysis showed that marking materials do not exhibit skid resistance behavior that is predictable solely from microtexture and macrotexture data. Apparently surface chemistry differences, which depend on formulation, play a significant role in skid resistance and therefore each type of material must be dealt with separately by using a prediction equation specific to that type or class of material.

Although a vast amount of data was available as a result of this study, in some cases, not enough data were available to develop meaningful prediction in the cases of the temporary tapes and the two component materials. Significant prediction equations that relate BPN or RMS (macrotexture) to SN_{64} were obtained for the various types of traffic paints, thermoplastics, and preformed plastics. The results are summarized in Figure 2. In some cases, BPN is sufficient to predict skid resistance for a given type of material, although in many cases the confidence of prediction can be improved by introducing a measure of macrotexture, such as RMS of macrotexture profiles. Since the latter may be difficult to obtain for some potential users, the poorer correlations that involve only BPN are included. In some cases little improvement was noted by including RMS and only the predictions by using BPN are listed.

Minimum Skid Resistance Levels

As shown above, pavement marking materials provide less skid resistance than the substrate on which they are deposited. This creates areas of differential friction across the surface of a pavement, which leads to potential hazards in vehicle operation. The degree of hazard present depends on the skid resistance of the substrate, the skid resistance of the marking material (relative to that of the substrate), and the area and geometry of the marking. The design of a roadway delineation scheme therefore requires recommendations, or guidelines, for setting minimum allowable skid resistance levels so that an appropriate marking material can be chosen.

Ideally, the recommendations would be expressed directly in terms of measurements obtained by using the test procedures described in previous sections. However, the performance of highway tires varies widely across the vehicle population, and the absolute value of measurements made from standard test procedures may not reflect the design requirements at a given site. In the subsequent discussion, the term coefficient of friction will be used to describe the frictional characteristics of the surface, instead of skid resistance, to emphasize that the highway design engineer may wish to provide his or her own interpretation and transformation of the standard test measurements.

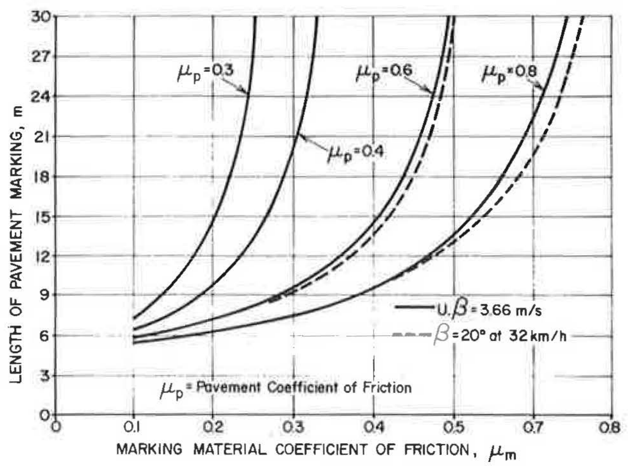
The effect of differential pavement friction on the response of four-wheeled and two-wheeled vehicles was studied by means of a simulation analysis. The analysis of four-wheeled vehicle behavior is discussed in a paper by Hayhoe and Henry (4) and only the major results will be repeated here. Details of the simulation models and vehicle parameters may be found in the report by Henry and others (3).

Cars in Skidding Maneuvers

Locked wheel skidding maneuvers, in which the brakes of the vehicle are released at some point during the skid, were considered to be the maneuvers most likely to lead to a serious hazard in car operation on differential friction surfaces. Two different maneuvers were chosen as typical of vehicle trajectories and roadway delineation met with in practice.

In the first maneuver the vehicle slides obliquely across a stripe of marking material 150 mm in width. Simulation results showed that, for all combinations of pavement and marking material friction, this configuration does not provide a significant hazard.

Figure 3. Recommended maximum lengths of pavement marking for safe operation of cars in skidding maneuvers, vehicle speed at inception of the skid = 88 km/h.



In the second maneuver the vehicle initially slides on bare pavement. The wheels on one side of the vehicle then slide onto a solid block of marking material while the wheels on the other side remain on the bare pavement. In this case, certain combinations of length of marked area, pavement friction, and marking material friction were found to create a definite hazard. Boundaries of safe operation are given in the design chart (Figure 3). Safe operation is indicated if a given combination of the two coefficients of friction and the length of differential friction surface falls to the right of the appropriate curve. Otherwise, unsafe operation is indicated.

The Figure 3 chart was constructed from the simulation results and illustrates the boundaries of safe operation for a specified set of operating conditions. A number of the assumptions made in constructing the simulation model and interpreting the results require validation. The chart should, therefore, be considered as giving a first approximation to the boundaries of safe operation.

Motorcycle Loss of Control on a Marking Stripe

An analysis of the motion of a motorcycle as it passes over an area of marking material is more difficult than an analysis for a car, because single-track vehicles are fundamentally unstable in roll. Without active control by the rider, the vehicle will simply fall over. Also, the locking of one or both of the wheels leads to rapid roll instability that cannot be corrected by the rider. Locked-wheel skidding maneuvers similar to those used in the four-wheel vehicle study were therefore not applicable. Rather, a maneuver in which the marking material caused a disturbance in the trajectory of the vehicle was required. An active steering controller, modeled in the simulation to stabilize the vehicle in roll, was a further departure from the methodology used in the four-wheeled vehicle study.

The maneuver chosen was as follows: set the vehicle in a steady state turn and then allow it to pass over a 150-mm-wide stripe of marking material at a given angle of attack. If the disturbance caused by the marking stripe was corrected by the steering controller, and the vehicle subsequently returned to the original steady state roll angle, the pavement-marking material configuration was acceptable. Otherwise, the configuration was not acceptable. The steady state roll angle in all simulation runs was set at 18.5°, which corresponded to a lateral acceleration of 0.3 g.

We concluded from the results of the simulation study that the risk of loss of control of a single-track vehicle as it passes over a pavement-marking stripe is increased by the following factors:

1. Decrease in the angle of attack,
2. Decrease in the marking material coefficient of friction,
3. Decrease in the pavement coefficient of friction,
4. Allowing of the vehicle to pass over the stripe more than once or to run over a number of stripes in succession, and
5. Decrease in forward speed.

Acceptance of these results depends on the confidence that can be placed in the procedure adopted for determining loss of control (i.e., whether or not the simulation steering controller was capable of generating a stable motion). Vehicle motion on a more extensive area of marking material than a single stripe was not investigated, but it seems reasonable to infer that a higher level of risk will prevail. Rider skill and experience clearly play a considerable role in the probability of an accident occurring on a given section of roadway, both as regards the rider's ability to anticipate road conditions and his or her ability to retain control once an emergency maneuver has been initiated. These considerations make it extremely difficult to formulate even the beginning of a general procedure for specifying acceptable levels of pavement marking material skid resistance for safe motorcycle operation.

However, it can be stated with a fair degree of certainty that a single-track vehicle operating on a pavement at a given level of acceleration (whether due to driving traction, braking, cornering, or any appropriate combination) is likely to become completely unstable if it passes across a marking material surface that has a coefficient of friction equal to or less than the vehicle acceleration measured in gravity units. There are two problems in trying to apply this statement: (a) How should the coefficient of friction of a typical motorcycle be defined and measured? and (b) Is a significant amount of differential friction allowable and, if so, how can safe levels be determined?

The first problem is a common one with four-wheeled vehicle operation, and a procedure developed for car tires would probably be equally applicable to motorcycle tires. The second problem is essentially concerned with human behavior relatively independently of vehicle behavior or vehicle-rider interaction. It depends mainly on whether a driver allows a consistent margin of safety against sliding when operating on various pavement surfaces. For example, when operating on a surface that has a coefficient of friction of 0.8, the driver might restrict vehicle accelerations to 0.6 g; on a surface that has a coefficient of friction of 0.6 he or she might restrict vehicle accelerations to 0.4 g. Other relations, such as the variation of safety margin with pavement friction, can also be postulated.

If such a relation could be established, the minimum allowable marking material coefficient of friction for safe motorcycle operation would be given by a function of pavement coefficient of friction (and, probably, by other highway design factors such as geometry), so that the vehicle would never operate on a surface whose coefficient of friction is lower than the maximum vehicle acceleration likely to be attained. On the other hand, if a consistent relation is found not to exist, or cannot be established, the minimum allowable marking material coefficient of friction could be given as the minimum allowable pavement friction for the sections of highway under consideration, irrespective of the existing or design pavement surface friction.

CONCLUSIONS

A data base for a large variety of pavement marking materials was established. A wide range of skid resistance levels was found, the lowest levels were for the hot extruded thermoplastic and the chlorinated rubber base paints that were used in the study. Glass beads and premixed beads and sand increased the skid resistance of the marking materials significantly. Spray thermoplastics provided higher skid resistance levels than hot extruded thermoplastics, due in part to the coarser texture produced by the spraying application. In the field both daily and seasonal variations in skid resistance were observed, and these variations should be accounted for in any field evaluation of marking materials.

The effect of accelerated laboratory polishing on marking material surfaces is much different from that on aggregate or unmarked pavement samples. Polishing tends to decrease the frictional resistance of beaded surfaces but tends to increase the frictional resistance of some unbeaded surfaces. Any laboratory evaluation of marking materials should include a light polishing to condition the samples. Accelerated weathering is not necessary as a conditioning step in a laboratory evaluation. Sample preparation is extremely important and should duplicate field application procedures as closely as possible. Preparation techniques can have a greater effect on BPN values than will differences in materials.

The marking materials studied in this project were grouped into six types: traffic paints, hot spray thermoplastics, hot extruded thermoplastics, preformed plastic, temporary tapes, and two-part systems. In analyzing the data and developing the predictor equations for skid resistance in terms of texture and BPN data it was necessary to treat each type separately. This resulted in six data sets, some of which were too small to provide significant correlations.

Predictor equations were developed by using linear regression techniques to predict SN_{64} from BPN values. Correlation coefficients for the more successful of these equations ranged up to 92. In some instances the prediction was improved by the inclusion of the macrotexture profile RMS.

When applied to pavements, marking materials cause a local reduction in skid resistance. The resulting differential frictions can create a hazard for drivers of automobiles and other four-wheel vehicles if the materials are applied to large areas such as gores, legends, and stop bars. Such applications should be avoided when possible, although a tentative design procedure has been developed for selection of materials that give safe levels of skid resistance. Current standards for such configurations should be reviewed in light of this finding. Lane delineation lines do not present a hazard for drivers of four-wheeled vehicles, even when the marking material skid resistance is extremely low. Almost any application of pavement marking materials will create a potential hazard for riders of single-track vehicles. Recommendations for minimum allowable levels of marking material skid resistance for safe operation of single-track vehicles could not be established. However, the skidding hazard presented by pavement markings to riders of single-track vehicles should be weighed against the safety benefit provided by the marking in the form of roadway delineation and warnings of safety hazards.

ACKNOWLEDGMENT

The research described in this paper was conducted as part of the Federal Highway Administration research project, Wet Friction of Pavement Marking Materials. Edward Harrigan served as technical monitor of this project and his assistance is greatly appreciated. We also express our appreciation to Prismo Universal Corporation for their assistance in applying the test materials.

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Publication of this paper sponsored by Committee on Surface Properties-Vehicle Interaction.

Tire Testing at Low Speed on an Ice Rink

GORDON F. HAYHOE AND JOHN J. HENRY

Procedures are described for measuring the performance of tire traction on an ice rink. Results are given from driving traction and locked wheel braking tests conducted at various speeds by using a modified road friction tester. Maximum test speed was restricted to 12 mph (19 km/h) by the small surface area of the ice rink, but the locked wheel braking results obtained are shown to be representative of higher speed tests if the test speed used is high enough that the tire force approaches its limiting (minimum) value. To enhance test repeatability, the sensing element of the transducer used to measure surface temperature should be completely frozen into the ice just below the surface. The ice surface should also be conditioned by running preliminary tests until the tire force measurements have reached a stable value. Contamination and damage to the ice surface from studded tire tests are described, and their effects on tire force generation and test repeatability are discussed.