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*Publication of this paper sponsored by Committee on Characteristics of Bituminous-Aggregate Combinations to Meet Surface Requirements.*

# Wet-Pavement Friction of Pavement-Marking Materials

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**A total of 39 formulations of 11 types of marking materials were studied in the laboratory and in the field. Field skid number measurements were made at three sites by using the Pennsylvania Transportation Institute Pavement Friction Tester. Laboratory and field measurements were taken to determine British pendulum numbers, microtexture, macrotexture, and static coefficient of friction. Laboratory polishing and accelerated exposure testing were also performed. A wet-friction data bank for typical pavement-marking materials was established. Based on an analysis of these data, it was found that wet friction can vary dramatically for different marking materials. The texture of the underlying pavement affects the friction of thinner marking materials (paints), but the wet-friction resistance of the thicker marking materials is unaffected by the texture of the underlying pavement. Reductions in skid resistance from the paints can persist even after the aggregate surface is exposed from wear. The wet friction of marking materials exhibits a daily and seasonal variability much like that of the pavement itself, and the variability must be accounted for when skid-resistance measurements are made.**

Many types of materials are used for pavement-marking purposes. Although these materials are routinely specified and tested in order to control their durability and visibility, little is known about their friction properties. The friction, or skidding resistance, of pavement surfaces has received considerable attention in recent years; this has resulted in improved test procedures and in surfaces that are more skid resistant. Well-marked pavements and highly skid-resistant pavement surfaces are both important safety features. However, the differential skid resistance that can develop between marked and unmarked pavement surfaces may, in certain circumstances, be a potential safety hazard.

The purpose of this paper is to report on the results of an extensive study of the wet-pavement friction of all types of pavement-marking materials. Both laboratory and field data are presented for a variety of pavement surfaces. The results are discussed in terms of the different levels of friction that can be developed by the different marking materials and the implications of these differences.

## WET-PAVEMENT FRICTION

The texture of a road surface is the most important characteristic that provides resistance to skidding in wet weather (1). For the purpose of designing surfaces for good skid resistance, it is convenient to define two texture classifications: macrotexture, which is related to the gradation of the coarse aggregate, and microtexture, which is determined by the surface characteristics of the exposed aggregate particles. It has been shown (2) that, for skid-resistance considerations, microtexture consists of that portion of the surface spectrum that has surface asperities <0.5 mm (0.02 in) and macrotexture consists of the portion that has surface asperities >0.5 mm.

Pavement skid resistance is quantified by its skid number (SN), which is defined as the ratio of the friction force and the vertical load that results when a locked wheel slides along a wetted pavement at a velocity V. The procedure for measuring the SN is specified by ASTM E274. For pavements it has been shown that the skid resistance decreases with speed according to the following relationship (3):

$$SN = SN_0 \exp\left[-(PNG/100)V\right] \quad (1)$$

where $SN_0$ is the zero speed intercept and PNG is the percentage of the normalized gradient, which is defined as

$$PNG = -(100/SN)(dSN/dV) \quad (2)$$

It has also been shown that $SN_0$ can be predicted by microtexture or British pendulum number (BPN) measurements as specified in ASTM E303. The value of PNG, which determines the rate at which skid resistance decreases with speed, is determined by the macrotexture of the pavement as measured by profile analysis or by the sand-patch method (4).

## EFFECTS OF MARKING MATERIALS ON SKID RESISTANCE

Pavement texture is altered at those locations where pavement marking materials are applied. As a result, there will be a difference in skid resistances between the marked and the unmarked areas of the pavement. Problems may arise when the friction forces available to all tires on a vehicle are not equal. If emergency stops, or other maneuvers, are attempted when the friction forces are significantly different at one or more of the tires, the directional control of the vehicle may be lost.

Marking materials of various types are applied in thicknesses ranging from 0.4 to 3 mm (0.016-0.125 in). Thinner applications, typical of traffic paints, permit the macrotexture to continue to show through to some extent but may alter the microtexture significantly. A surface dressing of glass spheres added for reflective purposes may also provide some texture until the spheres are worn away. At the other extreme, the thick materials such as the thermoplastics obliterate the pavement microtexture and macrotexture completely. After the surface dressing of glass spheres on thermoplastics has worn away, little texture remains, except for the texture provided by the aggregate used as a filler in the formulation of the thermoplastic.

## TYPES OF MARKING MATERIALS

Conventional traffic paints applied in a typical wet-film thickness of 0.5 mm (0.020 in) have a thickness of 0.3-0.4 mm (0.012-0.016 in) when dry. Glass spheres are applied to the wet paint to provide reflectivity. In some cases, finer glass spheres are also premixed with paint. Traffic paints are formulated with an alkyd resin or a chlorinated rubber base and are designed to dry by solvent evaporation or by solvent flash evaporation when the paint is heated above the normal boiling point of the solvent prior to spraying. Glass beads are either applied under pressure (by using a pressurized glass spray gun) or are dropped by gravity through a glass dispenser onto the wet marking material.

In order to achieve longer-lasting markings, thick plastic materials (polyvinyl chloride or ethyl cellulose) were introduced in the early 1950s. These materials are applied with an adhesive that may or may not be preapplied to the material. They also may be rolled during construction into the surface of flexible pavements in the final compaction. The preformed plastic, or cold-applied plastic, materials are currently available in thicknesses that range from 1.5 to 3 mm (0.06-0.125 in).

During the past 10 years, the use of thermoplastic materials has increased in the United States. These materials are applied in a molten state, either extruded onto the surface or sprayed under pressure. Glass and hard aggregate are included in the formulation to provide reflectivity and structural integrity to the material. Glass spheres are also applied to the surface while the material is still molten. Thermoplastics are applied at film thicknesses of 2.3-3.2 mm (0.090-0.125 in). These materials flow into the texture of the pavement, fill the irregularities of the surface, and cover the pavement aggregate completely. As in the case of the cold-applied plastic, the hot-applied thermoplastic produces a surface that, when newly applied, has its own frictional properties independent of the surface over which it is applied.

"Temporary" tapes, originally designed only for temporary use during construction projects, detours, etc., are also used for more permanent applications. These materials include aluminum strips that are painted and glass-sphere reflectorized on one side and provided with an adhesive on the other. Such tapes conform to the macrotexture of the pavement and allow the macrotexture to show through.

Two-component, chemically set materials are being used to a limited extent at present. New epoxy-polyester materials applied in the medium-thickness range of 0.75-1.5 mm (0.030-0.060 in) show promise for durable pavement-marking lines. The development of equipment for their application is needed before these materials will see widespread use.

## MEASUREMENT OF FRICTION OF PAVEMENT-MARKING MATERIALS

Measurement of the skid resistance of marking materials by using full-scale methods on actual installations is not possible with conventional skid-testing equipment. However, by using the Pennsylvania Transportation Institute's Pavement Friction Tester, a standard locked-wheel tester that has very high response instrumentation, it is possible to obtain SNs on very short installations. Installations 30 cm wide by 6 m long (1x20 ft) were placed on a variety of pavements and measured at speeds that ranged from 50 to 80 km/h (30-50 miles/h). Test methods appropriate for small areas include texture profile measurements and British pendulum testing.

Also of interest, particularly at crosswalks of city streets, is the pedestrian slip resistance. To evaluate the safety from the pedestrian's standpoint, the static coefficient of friction is required (5). A device developed at the National Bureau of Standards (NBS), the NBS-Brungraber Portable Slip-Resistance Detector, is applicable to measurements on small samples and can be taken into the field for testing on actual installations.

## TEST MATERIALS

Eleven different marking materials in a total of 39 formulations were evaluated in the laboratory and in the field. Material variables included in the study were

1. Type of marking material (such as paint, thermoplastic, cold applied),
2. Pigment color (white or yellow), and
3. Surface (beaded or unbeaded).

The different types of materials that were included in the study are summarized below.

| Material | Code | Number 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-polyesters | TP | 4 |

Emphasis was placed on the hot-sprayed, hot-extruded, and cold-applied materials because they are being used extensively, are long lived and, because of their thickness, have the greatest potential for producing low levels of friction.

Each material was evaluated both in the laboratory and in the field. Three field-test sites were used. Seventeen marking materials were applied in and out of the wheel tracks on PA-45, a six-year-old dense-graded asphalt pavement that has an $SN_{40}$ [SN at 40 miles/h (64 km/h)] of approximately 40. Eight materials were placed in and out of the wheel tracks on PA-871, a four-year-old portland cement concrete pavement that was finished with longitudinal brooming. The $SN_{40}$ for this pavement is approximately 55. The third test site was the Pennsylvania Transportation Research Facility test track, which has different surfaces that range in $SN_{40}$ from 30 to 65. The surfaces include portland cement concrete, an open-graded friction course, a dense-graded asphalt concrete, and a surface coated with Jennite.

Commercial application equipment was used to apply the paints, the two-part epoxy-polyesters, and the hot-sprayed and hot-extruded thermoplastics. The cold-applied materials and the temporary tapes were simply pressed into place. The field-test stripes were 152 mm (6 in) wide by 6 m (20 ft) long. In order to make the laboratory samples as representative of the field samples as possible, the paint and the hot-sprayed and two-part materials were sprayed onto panels placed on the pavement just ahead of the field test stripes. This was not possible with the extruded materials, which were extruded in the laboratory by using material from the same production batches as those used in the field.

Four different laboratory panels were used to provide a variety of surface textures. Duplicate panels were prepared for each material tested. The majority of the panels were 16-gage galvanized steel plates 152 mm (6 in) long by 102 mm (4 in) wide. A limited number of panels were made in the laboratory with (a) broomed portland cement concrete, (b) coarse-textured asphalt concrete and, (c) fine-textured asphalt concrete. These surfaces were designed to simulate texture extremes that might be encountered in the field.

## TESTING PROGRAM

The testing program was designed to provide information about the friction resistance and texture of the marking materials. Specific test procedures included

1. SN measurements (ASTM E274) at 48, 64, and 80 km/h (30, 40, and 50 miles/h) at all field sites;
2. Use of the NBS-Brungraber Portable Slip-Resistance Detector at all field sites and for all laboratory panels;
3. Microtexture and macrotexture profile measurements at selected field samples and for selected panels;
4. BPN (ASTM E303) at all field sites and for all laboratory panels; and
5. Atlas Twin-Arc Weatherometer exposure on selected laboratory panels followed by Brungraber, BPN, and texture measurements.

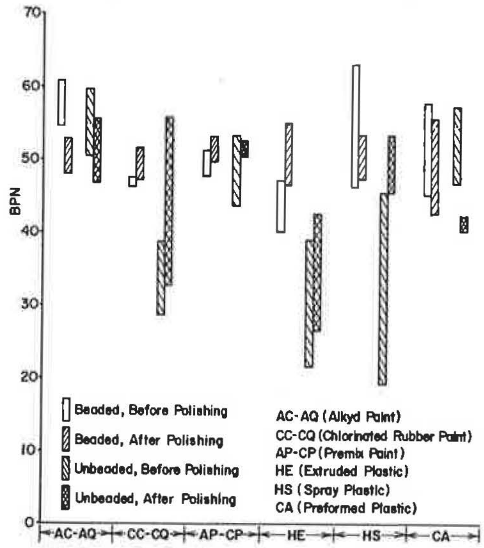
$SN_{40}$ measurements were obtained on 14 different days in the fall of 1978 and the spring of 1979 in order to determine seasonal and daily variations in skid resistance. $SN_{30}$, $SN_{40}$, and $SN_{50}$ data were obtained on several different days in order to establish PNGs for each of the field-test stripes. The field BPN, Brungraber, and texture data were taken in the fall of 1978 and the spring-summer of 1979.

In order to simulate wear in the field, all of the laboratory panels were subjected to polishing by using the Pennsylvania State University Reciprocating Pavement Polisher. Preliminary testing indicated that terminal polishing was obtained after 3000 passes with 30-μm silica grit. All the panels were subsequently tested by means of this polishing sequence. BPN and Brungraber data were obtained for all of the panels before and after 200 h of weatherometer exposure. After exposure the panels were polished and the BPN, Brungraber, and texture data obtained.

## RESULTS

BPN data for the metal plates are shown in Figure 1. Each bar shown in the graph represents data from duplicate test panels. Because the yellow and white materials were not significantly different, data for the white and yellow formulations were combined. Therefore, each bar in Figure 1 represents data from a minimum of four panels. Five different materials are represented by the hot-extruded plastics (HE) data, 3 materials by the hot-sprayed plastics (HS) data, and 10 materials by the cold-applied (CA)

Figure 1. BPN results for steel laboratory panels.




data. The temporary tapes (TT) and CA materials are not shown because they are not readily classified as beaded or unbeaded.

The BPN data for most of the beaded materials in Figure 1 are in the range of 50 ± 5, both before and after polishing. It is apparent that, when beaded materials are applied to a smooth substrate, the characteristics of the beads predominate and their characteristics are not affected by polishing. There is little to be learned about beaded marking materials when they are applied to a smooth substrate.

The data for the unbeaded surfaces in Figure 1 reflect the friction of the marking material itself. The low values before polishing shown by the chlorinated rubber are difficult to explain; however, this trend was observed in the field. Similarly, there is no adequate explanation for the increase in the BPN data for the various chlorinated rubber paints (CC and CQ) after polishing. The low BPN results for the HE are also surprising, but again similar trends were observed in the field. The increase in the BPN results after polishing for the HS is undoubtedly the result of exposing the filler in the HS material.

In summary, Figure 1 indicates that some marking materials, notably the chlorinated rubber and the HE, have inherently low BPN values. As long as the beads are not worn from the surface, polishing has little effect on the BPN of the different materials. Finally, if filler materials are exposed during laboratory polishing, an increase in skid resistance may result, as shown with the HS.

The results presented in Figure 2 allow a comparison of the effects of surface texture on the BPN of the different beaded marking materials. Once again, little variation is observed between the different materials; the average holds at about 50 ± 5 points. The large BPN values obtained for the CC, CQ, AP, and CP paints on the coarse asphalt concrete surfaces were expected because the paint was too thin to fill the texture of the surface. Two results that are hard to explain are the reduced BPN values (by 10 points) obtained on the fine asphalt concrete for the AC, AQ, CC, and CQ materials. One possible explanation is a partial dissolving of asphalt on the surface; this process reduces the friction of the paint. Otherwise the surfaces in Figure 2 reflect the friction of the glass beads (average BPN value of 50 ± 5).

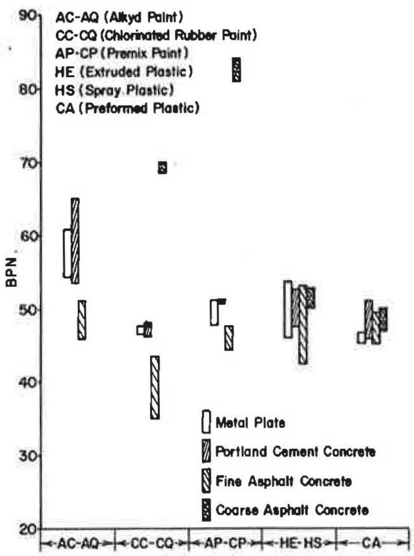



Figure 2. BPN results for beaded materials on surfaces with different textures.

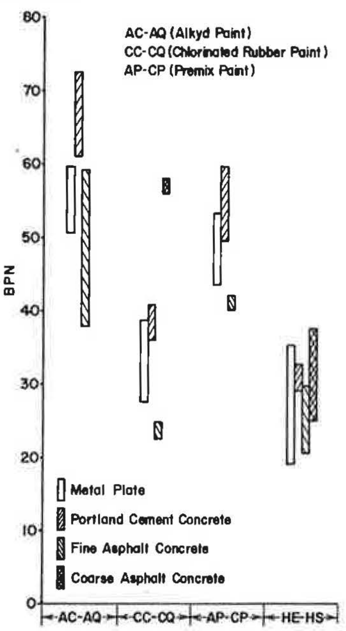



Figure 3. BPN results for unbeaded materials on surfaces with different textures.

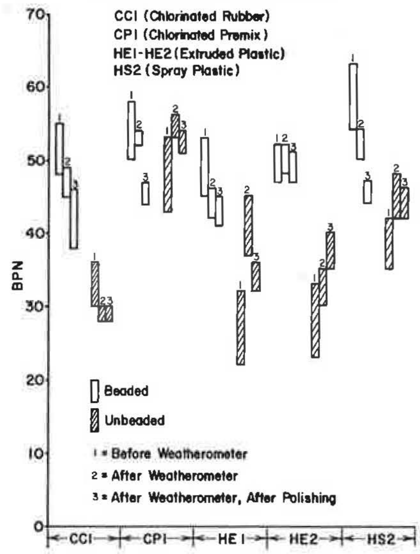



Figure 4. BPN results for panels subjected to weatherometer exposure.

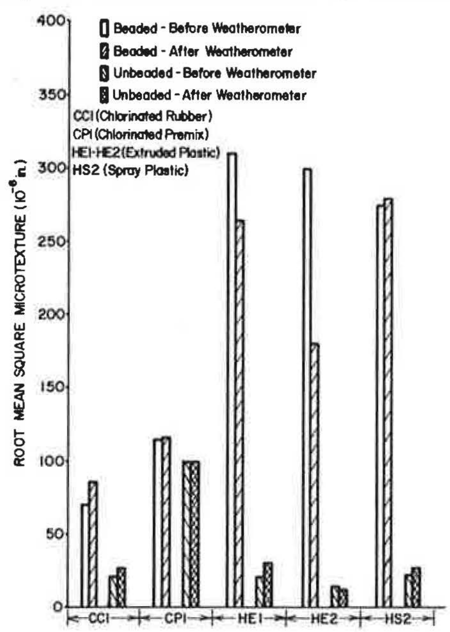



Figure 5. Texture for weatherometer samples before and after exposure.

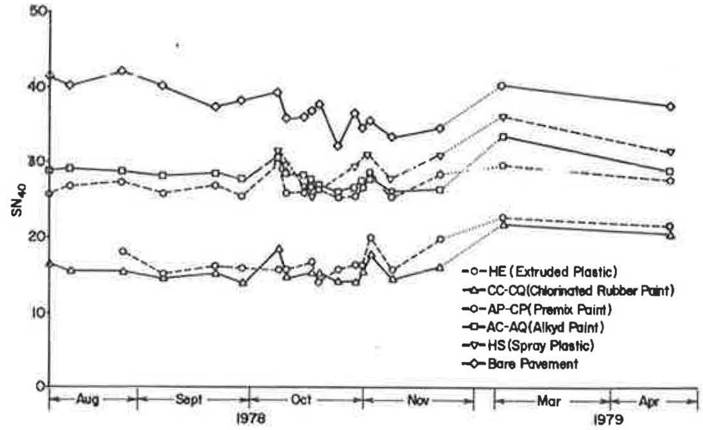
The BPN results presented in Figure 3 are for unbeaded materials applied to the four laboratory surfaces. These unbeaded surfaces show a greater variability than do the corresponding beaded surfaces of Figure 2. Texture effects are more pronounced for the paint materials; however, as expected, the thick thermoplastic materials are not affected by the texture of the surface. A decrease in BPN for the paints applied to the fine-textured asphalt-concrete surface is also apparent for the unbeaded surfaces.

The results presented in Figure 4 were obtained from steel panels after 250-h exposure in the Atlas Twin-Arc Weatherometer. BPN data were obtained before exposure, after exposure, and after exposure and polishing. Both beaded and unbeaded surfaces were tested. Visually, little change was obtained in the surfaces as a result of weathering. There was no observable loss of beads during exposure. Although some change occurred in the BPN results after exposure, the changes are not considered significant. Changes that resulted from polishing were approximately the same as for the unweathered plates after polishing. Only the HE formulation 1 (HE1) increased significantly after weathering, but the increase was largely lost after polishing. Based on the results shown in Figure 4, weatherometer data do not appear to be required in order to specify the friction of marking materials.

Microtexture data for the weatherometer samples, before and after exposure, are given in Figure 5. In general, little change in texture occurred during weathering, and the texture of the beaded surface was much higher than that of the unbeaded surfaces. Figure 5 also substantiates the hypothesis that weatherometer data are not required in order to specify the friction of marking materials.

The $SN_{40}$ results shown in Figure 6 were

Figure 6. Daily variations in $SN_{40}$ on PA-45.




obtained over a period of nine months that started just after the application of the marking materials. In this case the $SN_{40}$ for the unmarked control surface averaged just under 40. The lowest $SN_{40}$ values were obtained for the CC and CQ paints and, in spite of nine months' exposure, little improvement in skid resistance is shown. This result is very surprising in view of the fact that those paints did not obscure the texture of the pavement and that during the nine-month period there was considerable wearing away of the paint. In fact, the skid resistance of the CC and CQ paints was almost identical to that of the HE material.

The skid resistances of the AP, CP, AC, AQ, and HS materials were all less than that of the control surface. None of the marking materials approached the unmarked control surface even after nine months' exposure, indicating that reduced skid resistance is a long-term effect even for the relatively thin paints.

Both seasonal and daily variations were observed for the marking materials, as indicated in Figure 6. The seasonal trends for the marking materials appear to follow the same trend as the control surface; however, the daily trends appear somewhat mixed. Time of testing does appear to be an important consideration for marking materials and is probably associated with changes in local weather conditions.

Further research is needed to explain the wide variations in skid resistance among the various materials. Such explanations would aid in the more important task of developing marking materials that are more skid resistant.

Based on the observations made during the research study, it can be concluded that

1. Different marking materials have different characteristics and this can affect skid resistance;
2. Friction of beaded surfaces is determined primarily by the beads, even for relatively thin materials such as paints;
3. Reductions in skid resistance, even for the relatively thin paints, are not confined to the time period just after application but may last over a relatively long period in spite of considerable surface wear;
4. Accelerated exposure testing is not helpful in specifying the friction of marking materials;
5. Effects of daily and seasonal variations in the skid resistance of marking materials must be accounted for in making skid-resistance measurements; and
6. Certain marking materials, because of their low skid resistance, may be a safety hazard if applied over large areas, such as gore areas.

## ACKNOWLEDGMENT

The research described in this paper was conducted as part of the Federal Highway Administration research project on Wet Friction of Pavement-Marking Materials. Edward Harrigan served as technical monitor of this project, and his assistance is greatly appreciated.

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*Publication of this paper sponsored by Committee on Characteristics of Bituminous-Aggregate Combinations to Meet Surface Requirements.*