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# Wear-Resistant and Skid-Resistant Highway Pavement Surfaces

*An NCHRP staff digest of the essential findings from an interim report on NCHRP Project 1-12(3), "Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces," by C. J. Van Til, B.J. Carr, and B. A. Vallerga, Materials Research and Development, Oakland, California*

## THE PROBLEM AND ITS SOLUTION

Traffic density and the use of winter traction aids contribute to accelerated polishing and wear of highway pavement surfaces. The resulting loss of surface texture reduces tire-pavement friction, particularly when wet. Channelized traffic can also produce wheelpath depressions or ruts that may be detrimental to vehicle control and permit ponding of water with adverse safety effects. In the interest of highway safety, it is essential that economical and effective procedures be provided for correcting polished or worn surfaces and that new pavement surfaces be designed and constructed to retain acceptable levels of resistance to wear and polishing. Few highway agencies have sufficient experience and research information to support the design, construction, and maintenance of highly wear-resistant and skid-resistant pavement surfaces required to accommodate the needs of traffic throughout the life of the pavement. The objective of NCHRP Project 1-12(3) is to identify and evaluate procedures for improving the resistance to wear and polishing of new pavements and for correcting worn or polished surfaces.

Phase I of the study consisted of an extensive review of relevant literature for the purpose of identifying the best current prospects for improved wear- and skid-resistant pavement surfaces and new and innovative procedures that appear promising but need further evaluation. The interim report, describing the findings of Phase I, contains a method for classifying pavement systems with regard to wear and skid resistance, tentative performance criteria, and recommendations for use of the systems judged to be most suitable for practical application. It also contains an annotated bibliography of more than 500 items on the subject and recommendations for further evaluation of more innovative pavement systems.

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## FINDINGS

As information on pavement systems was collected during the literature review, a method was developed for their classification for the purpose of simplifying the comparison and evaluation of the systems. The major categories consist of the systems suitable for remedial treatment of existing pavements and those applicable to new construction. Subcategories are: (a) types of systems, such as surface alterations, cover materials, or new surfaces; and (b) generic descriptions, such as grooving, thermoplastic binders, and nonthermoplastic binders.

During the evaluation process the researchers determined that performance criteria for wear-resistant and skid-resistant pavement systems should consider many factors, including skid-resistance, hydroplaning potential, studded-tire wear, effective life, cost, application procedures, availability of materials and equipment, maintainability, riding quality, tire noise, tire wear, and appearance. Tentative guidelines regarding skid resistance requirements in relation to operating speeds can be found in Table 1 of NCHRP Synthesis 14, "Skid Resistance." Criteria for hydroplaning potential are expected eventually to be expressed in terms of texture, pavement surface drainage, rainfall, and traffic speed. No satisfactory solution to the problem of studded-tire wear has yet been discovered. The remaining factors may be used as a basis for selection from among systems that satisfy the minimum requirements for skid resistance and hydroplaning potential.

After identifying and classifying the various wear- and skid-resistant pavement systems, they were evaluated on the basis of available information and ten systems were selected as being most suitable for immediate practical application. The major criterion used in the selection process was at least five years of satisfactory performance in at least three full-scale field applications. The selected systems were judged to be capable of producing satisfactory initial microtexture for high-speed traffic operations and satisfactory initial macrotexture to inhibit hydroplaning at normal operating speeds. The systems vary considerably in their resistance to wear and polishing. All are suitable for minimum or normal exposure categories, such as most city streets and rural highways with no steep grades, sharp curves, or unusual hazards. Several of the more costly systems are suitable for use in special or critical exposure categories, such as Interstate and high-speed highways, steep grades, sharp curves, high-speed merging lanes, and high-speed approaches to toll gates and other stopping locations.

Following are brief descriptions of the ten systems selected as suitable for immediate practical application:

1. Portland cement concrete, optimum design (wire broom finish or equivalent) - a conventional portland cement concrete in which special consideration to wear and skid resistance is given in the selection of the fine aggregate and the final surface texture is obtained by special wire-bristle brooms or other texturing devices.
2. Dense-graded asphaltic concrete, optimum mix design - a conventional dense-graded, hot plant-mixed asphaltic concrete in which special consideration to wear and skid resistance is given in the selection of the component aggregates and in the design of the mixture.
3. Open-graded asphaltic concrete - a hot plant mixture of asphalt cement and open-graded aggregate, in which special consideration to wear and skid resistance is given in the selection of the aggregate.
4. Skip-graded asphaltic concrete - a hot plant mixture of asphalt cement and skip-graded aggregate, in which special consideration to wear and skid resistance is given in the selection of the coarse aggregate and of the aggregate gradation.
5. Asphaltic concrete with rolled-in precoated chips - a skip-graded asphaltic

concrete mixture, followed by application, after initial placement and before rolling, of cold aggregate that has been precoated with an asphalt binder, and in which special consideration to wear and skid resistance is given in the design of the asphaltic concrete mixture and in the selection of the aggregate to be used as precoated chips.

6. Epoxy-modified asphaltic concrete - a hot plant-mixed conventional dense-graded aggregate and epoxy-modified asphalt binder, in which special consideration to wear and skid resistance is given in the selection of the aggregate.

7. Asphalt seal coat - the application of asphalt binder, followed immediately by an application of aggregate that has been selected with special consideration to wear and skid resistance.

8. Rubberized asphalt seal coat - the application of rubberized asphalt binder, followed immediately by an application of aggregate that has been selected with special consideration to wear and skid resistance.

9. Epoxy-asphalt, calcined-bauxite chip seal - the application of an apoxy-modified asphalt binder, followed immediately by an application of a specific calcined-bauxite aggregate.

10. Sawed longitudinal grooves - the sawing of a series of shallow, closely spaced, paralled grooves in the surface of a portland cement concrete pavement.

The interim report contains additional recommendations for use of each of these systems, including the conditions for which the system is applicable and guidelines for material and construction specifications. Because aggregates comprise more than 90 percent of a pavement mixture, their selection is of primary importance in the design of a wear- and skid-resistance surface. Appendix C of the interim report provides guidance in aggregate selection. (Also, see Chapter Six, "Design and Construction of Skid-Resistant Surfaces," in NCHRP Synthesis 14.) Aggregates have been divided into the following five groups according to their polish resistance:

Group I. In this group are those aggregates with outstanding ability to resist polish wear. Some of these materials are practical only for limited use in critical locations because of the high cost of manufacture or transportation. They are generally a heterogeneous combination of minerals, with a coarse grained microstructure of hard particles bonded together by a slightly softer matrix. Aggregates falling in this group are corundum-rich and include calcined bauxite (synthetic) and emery (natural). Group I aggregates are typified by those developed for, or used by, the grinding-wheel industry.

Group II. This group comprises a minority of the types currently used for highway paving and provide significantly better-than-average resistance to polish wear. Synthetic aggregates in this group are some air-cooled steel blast furnace slags and some expanded lightweight shales. Natural aggregates in this group are many of the coarse- and medium-grained sedimentary rocks, and particularly crushed sandstone, arkose, graywacke, and quartzite from formations providing good durability and abrasion resistance.

Group III. This group consists of many of the aggregates currently used for asphaltic concrete and portland cement concrete paving, except those included in Groups I and II. They have a satisfactory resistance to polish wear for all but the most severe conditions. The natural aggregates forming this group provide "average" resistance to polish wear and include coarse-grained, dense igneous and metamorphic rocks of the granite, granite gneiss, granodiorite, grano-diorite gneiss, diorite, and diorite gneiss types showing good integrity and an absence of pronounced foliation.

Group IV. This group comprises all remaining aggregates, with the exception of Group V, and may be described as exhibiting "lower-than-average" resistance to polish wear but still useable for paving purposes.

Group V. Aggregates associated with low polish resistance comprise this group. Typical are carbonaceous aggregates including most limestones and dolomites, and uncrushed, rounded, and water-worn gravels. Their use should be avoided when skid resistance and resistance to polish wear are required. Where other aggregates are limited in availability, they are often used for lower courses of pavements where no exposure to traffic occurs.

This classification may be employed as a guideline for the selection of fine aggregate to produce polish-resistant portland cement concrete where the surface mortar is a more important factor in resistance to polish wear and in skid resistance than is the coarse aggregate. For asphaltic concrete, asphalt surface treatments, and similar systems, it is the coarse aggregate that is the more important in this selection.

## APPLICATIONS

The systems selected for immediate application are not all equally suited for all service conditions. Some are applicable to remedial treatment of worn or polished surface, some to new construction, and in a few cases for special situations. The major factors or properties to be considered when the ten selected systems are used as remedial treatments for worn or polished surfaces are given in Table 3 together with estimated values for each property. The estimated values are based on information obtained from published literature and should be revised when not consistent with local experience. For example, open-graded aspaltic concrete is rated quite low with regard to relative wear in wheel tracks due to some early experiences with this type of surface. More recent experience in areas where this type of surface is used extensively may not be consistent with this rating.

The selection of an optimum system for a specific location depends on many interrelated factors. It is possible that a pavement most resistant to wear from studded tires has a low resistance to the polishing action of high-speed traffic. The calcined-bauxite seal is judged to be highly wear and skid resistant, but is very costly. Its use on low-volume low-speed residential streets with a low accident risk would not result in best use of available materials and funds. The open-graded asphaltic concrete surface is judged to have the highest resistance to hydroplaning and should receive major consideration when drainage of water from the pavement surface is a problem.

To assist in the selection of a suitable pavement system for a particular location, a guide has been prepared in chart form (Table 4). The factors considered in the table are the comparative properties of the ten candidate systems, the relative accident risk at the location, and the specific conditions of the location for both restoration of existing surfaces and construction of new surfaces.

To use the chart as a guide for selection of optimum systems, two decisions must first be made: the conditions, in terms of those included in the chart, which are relevant to the location being considered; and the relative accident risk (high, H, intermediate, I, or low, L) at this location. The choice of system may then be made on the basis of the priorities indicated in the columns under each system, with "1" designating first priority for selection and higher numbers corresponding lower priorities. For example, if the conditions are an existing pavement with a highly polished surface, and a high relative accident risk, the chart is entered at the first horizontal row headed "Highly Polished" and the priorities for selection are found in the vertical columns under "H" for each system. In this case there is one system with first priority (epoxy-modified asphalt calcined-bauxite chip seal); one system with second priority (asphaltic concrete with rolled-in precoated chips); and three systems with third priority (dense-graded asphaltic concrete, skip-graded asphaltic concrete, and epoxy-modified asphaltic concrete). All other systems are indicated as not recommended or not applicable for this purpose. The final selection may then be further tempered by local considerations, such as availability of materials, availability of contractors with experience in construction of the system, costs of materials, and local experience. For example, if recent experience indicates good performance from open-graded asphaltic concrete, it should be rated higher for some of the conditions than shown on the chart.

TABLE 3

COMPARATIVE PROPERTIES OF WEAR- AND SKID-RESISTANT SYSTEMS
FOR IMMEDIATE IMPLEMENTATION, USED AS REMEDIAL TREATMENTS

| PROPERTY | SYSTEM | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PCC, Optimum Design | Dense-Gr. AC, Opt. Design | Open-Graded AC | Skip-Graded AC | AC with precoated chips | Epoxy-modified AC | Asphalt Seal Coat | Rub. Asph. Seal Coat | Epo.-Asph Calc.-Baux. Seal | Sawed Long. Grooves |
| Applied cost range ($/sq. yard)[1,2] | NA | 0.75-1.50 | 0.50-1.20 | 1.00-1.75 | 2.00-2.50 | 6.75-11.25 | 0.20-0.30 | 0.50-0.75 | 6.00-10.00 | 0.50-1.00 |
| Estimated effective life (years)[2] | 5-15 | 5-15 | 5-10 | 5-15 | 10-15 | >10 | 2-5 | 2-7 | 7-13 | 4-7 |
| Relative wear factor[2,3,4] | 3 | 3 | 4 | 2 | 1 | 2 | 6 | 5 | 1 | 4 |
| Relative resistance to hydroplaning[4] | 4 | 4 | 1 | 4 | 3 | 4 | 2 | 2 | 2 | 2 |
| Estimated Skid Number range ($SN_{40}$-ASTM trailer)[2] | 50-65 | 50-65 | 55-65 | 50-65 | 55-70 | 55-65 | 50-65 | 50-60 | 65-80 | 40-50 |
| Relative skid speed gradient[5] | 3 | 3 | 1 | 3 | 2 | 3 | 2 | 2 | 1 | 3 |

[1]In terms of usual resurfacing thicknesses for plant-mixed and seal coat systems and of cost experience with grooving.

[2]Estimated assuming similar aggregates (except for the system where calcined-bauxite only is specified), with effective life varying with conditions such as traffic density, climate, etc.

[3]Wear in wheel track due to abrasive action of normal traffic (1== most resistant to wear).

[4]Ratings are on the basis of "1" being most desirable.

[5]Indicates fall-off of skid number with increasing speed (1 = least change).

TABLE 4

SELECTION GUIDE FOR OPTIMUM SYSTEMS FOR WEAR- AND SKID-RESISTANT SERVICE

| | CANDIDATE SYSTEMS | PCC, Optimum Design | Dense-Gr. AC, Opt. Design | Open-Graded AC | Skip-Graded AC | AC with precoated chips | Epoxy-modified AC | Asphalt Seal Coat | Rub. Asph. Seal Coat | Epo.-Asph., Calc.-Baux. Seal | Sawed Long. Grooves |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | RELATIVE ACCIDENT RISK | H I L | H I L | H I L | H I L | H I L | H I L | H I L | H I L | H I L | H I L |
| Existing Pavement Considerations | Highly Polished | X X X | 3 1 1 | X 2 2 | 3 1 1 | 2 1 2 | 3 3 X | X X X | X X X | 1 2 3 | X X X |
| | Some Polish-Wear | X X X | 3 1 2 | 3 2 2 | 3 2 3 | 2 2 3 | 4 4 X | X X 1 | X X 1 | 1 3 X | X X X |
| | Studded Tire Wear | X X X | 3 3 2 | X X X | 2 2 2 | 1 1 1 | 2 2 2 | X X X | X X X | X X X | X X X |
| | Climatic Damage e.g., Scaling, Ravelling | X X X | 3 1 1 | X X X | 2 1 2 | 2 2 2 | 1 3 X | X X 3 | X X 3 | 1 3 X | X X X |
| | Sharp Curves | X X X | X X 3 | X 3 3 | X X X | 2 2 3 | X X X | X X 1 | X X 1 | 1 1 2 | 1 1 2 |
| | Hydroplaning Potential | X X X | X 4 5 | 1 1 2 | X X X | 3 3 4 | X X X | X X 1 | X X 1 | 2 2 3 | 1 1 3 |
| | Flushed Asphalt | X X X | 3 1 1 | 3 1 1 | 3 2 2 | 2 2 3 | 3 3 X | X X X | X X X | 1 2 X | X X X |
| | Oil Dripping Deterioration | X X X | X X X | X X X | X X X | X X X | 2 2 2 | X X X | X X X | 1 1 1 | X X X |
| | Weight or Thickness Limitation | X X X | 3 2 2 | 3 2 2 | 3 3 3 | 3 3 X | 2 2 X | X X 2 | X X 1 | 1 1 3 | X X X |
| | Flash Freezing (e.g., bridges) | X X X | X 3 3 | X X X | X 3 3 | 2 2 4 | X 4 X | X X 3 | X X 2 | 1 1 1 | X X X |
| Anticipated Service Conditions for New Construction | High Polish-Wear | 3 2 1 | 3 2 1 | X 3 2 | 3 2 1 | 2 1 2 | 3 2 X | X X X | X X X | 1 3 X | X X X |
| | Some Polish-Wear | 2 1 1 | 2 1 1 | 3 2 1 | 2 2 1 | 1 3 X | 3 X X | X X X | X X X | 1 3 X | X X X |
| | Studded Tire Wear | 3 2 1 | 3 2 1 | X X X | 2 1 1 | 1 1 2 | 2 3 3 | X X X | X X X | X X X | X X X |
| | High-Speed Curves | 2 1 1 | 2 1 1 | X 3 2 | 2 1 1 | 1 2 3 | 3 4 X | X X X | X X X | 1 3 X | 3 4 X |
| | Flexible (Orthotropic) Bridge Deck | X X X | X X X | X X X | X X X | X X X | 1 1 1 | X X X | X X X | 1 1 1 | X X X |
| | Weight Limitation (Bridges) | 1 1 1 | 3 3 3 | 3 3 3 | X X X | X X X | 2 2 2 | X X X | X X X | 1 1 1 | X X X |

Note: "X" in any column indicates not recommended or not applicable for this purpose.
See text for explanation of how chart was prepared and suggestions for use.