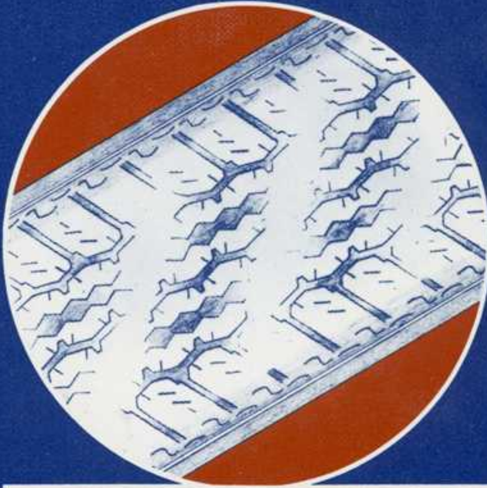

The TIRE PAVEMENT INTERFACE

Pottinger/Yager, *editors*

ASTM STP 929

THE TIRE PAVEMENT INTERFACE

A symposium sponsored by
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Traveled Surface Characteristics
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Foreword

The symposium, Where Performance Begins: The Tire Pavement Interface, was presented at Columbus, OH, 5–6 June 1985. The symposium was sponsored by Committees E-17 on Traveled Surface Characteristics and F-9 on Tires. Marion G. Pottinger, The BFGoodrich Co., and Thomas J. Yager, NASA Langley Research Center, served as chairmen of the symposium and are editors of the resulting publication.

Related ASTM Publications

Frictional Interaction of Tire and Pavement, STP 793 (1983), 04-793000-37

Pavement Surface Characteristics and Materials, STP 763 (1982), 04-763000-47

Applied Surface Analysis, STP 699 (1980), 04-699000-39

Tire Reinforcement and Tire Performance, STP 694 (1980), 04-694000-37

Rubber and Related Products: New Methods for Testing and Analyzing, STP 553 (1974), 04-553000-20

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Overview

Conditions at the tire pavement interface help to prescribe solutions to one of the most economically important sets of boundary value problems in the world. Quite literally the whole modern world turns on this boundary. This boundary is fundamental to current land and air transportation.

The fundamental importance of the tire pavement interface is illustrated by the interest it holds for many groups: highway engineers, tire engineers, automotive engineers, environmentalists, politicians, and so forth. Unfortunately, in this age of specialization each group tends to talk only to itself, thus, reinforcing parochial viewpoints and often preventing synergistic solutions to transportation problems.

The current situation cries out for a systems approach integrating the interests and insights of all groups. The synergism that would occur might produce an improved transportation system at no increase in total cost. Certainly, more creative ideas would be produced.

Based on their belief that better inter-group communication is a necessity to produce a systems approach to tire dependent transportation, the symposium organizers formulated two goals:

1. The papers had to represent many views of various tire pavement interface associated transportation problems.
2. There had to be a balance of both review and research papers so that the needs of both new and experienced workers would be met.

The symposium papers on traction, wear, interfacial mechanics, and tire pavement interaction generated noise and vibration will be discussed in an integrated fashion.

Technical Basics

The tire pavement interface is a variable boundary in which energy is changed from one form to another in response to the kinematics of rolling contact between a flexible thick shell (the tire) and a semi-rigid structure (the pavement). Both the tire and the pavement have surfaces with significant texture. The relationship between the tire and the pavement is directly dependent on the motions of the vehicle on which the tire is mounted and on the demands of the vehicle operator. With all feedbacks considered, this is a very complex dynamic problem, which is also affected by weather, surface chemistry, economics, and a host of other factors.

Texture is a key feature of the tire pavement interface. It influences almost every performance problem.

The pavement has texture of importance to tire pavement interactions covering wavelengths from 10 m to 0.01 mm. The tire has tread pattern (texture) with wavelengths from 2 m to 1 mm. In addition internal irregularities introduced into the tire by manufacturing imprecision (nonuniformities) can make a tire act as if it had an additional texture in the 2 m to 1 mm range.

The textural wavelengths between 10 m and 10 mm contribute to noise and vibration problems as reported by Pottinger [*1*]. The longer wavelengths can contribute to vehicle control problems if their amplitudes are large enough to generate vibration induced changes in vehicle control forces.

The tread and pavement surface wavelengths between 40 and 1 mm are primary contributors to the drainage of water out of the tire pavement interface. As Henry [*2*] observes, these wavelengths (macrotexture) are crucial to the design of pavements with good wet traction characteristics.

Veith [*3*] states that the wavelengths below 1 mm, and particularly those below 0.1 mm (microtexture), are crucial to friction and wear. It is friction that makes the use of tires practical since the tires generate the vehicle control forces from frictional shear stresses induced by the tire's unique kinematic interactions with the pavement. Neglecting lubrication and contamination, friction arises from adhesion to, deformation of, and abrasion of the tire tread compound by the pavement. During this process, viscoelastic behavior of the tread compound excited by the pavement microtexture plays a dominant role [*3*].

Traction

Traction is the term used to describe the practical generation of vehicle control forces from tire pavement interfacial friction. Traction considers the tire, the pavement, lubrication, contaminants, weather effects, and vehicle control demands.

In this STP the traction papers deal primarily with assessing the traction characteristics of pavements based on standardized tests performed with standard tires, time/seasonal stability of pavement performance, the effect of rubber contamination of the pavement surface on pavement performance, and the effect of footprint shape on hydroplaning velocity. Wet traction was emphasized because of its great importance to safety. About 14% of all fatal automobile accidents occur when roads are wet [*2*], which is only about 3% of the time.

The three papers directed at assessing pavement effects on available wet traction [*2,4,5*] conclude that there is a necessity for characterizing both macrotexture and microtexture in order to properly describe a pavement.

The need to characterize both textures in order to properly study wet traction is easily understood in light of Moore's wet traction model [6], which is discussed by Lenke and Graul [5]. In this model the tire pavement interface is divided into three zones. From front to rear of the interface these zones are a sinkage zone where the water drains out from under the tire, a draping (squeeze film) zone where the tire drapes over the major asperities and the minor asperities penetrate the remaining thin film, and a contact zone in which more or less normal dry road contact occurs.

The size of the sinkage zone depends on vehicle speed, tire inflation pressure, and interfacial drainage characteristics. If this zone grows to encompass the whole tire pavement interface zone, the tire hydroplanes and generates no control forces. From the pavement viewpoint macrotexture or grooving is the source of interfacial drainage. Thus, maintaining adequate macrotexture augmented with grooving in crucial locations is the first step in providing a pavement with good traction characteristics. However, when adding macrotexture, tire pavement generated noise and vibration must be kept in mind [1]. If the macrotexture becomes excessive, inordinate noise and vibration will occur in both the vehicle and environment. This is the highway engineers' problem. The tire and vehicle design engineers can not eliminate this noise. Also, longitudinal grooving causes a vibration problem known as "L. A. Wiggle" [1]. This is a tire pavement interaction problem that can be easily solved as long as the tire and highway engineers communicate.

Recognizing that high speeds and low tire tread depths are associated with skidding accidents, the highway community is using the smooth treaded tire as in ASTM Specification for Smooth Tread Standard Tire for Special-Purpose Pavement Skid Resistance Tests (E 524) smooth tire more and more in skid testing [2,4,7]. The ASTM E 524 tire represents the worst case; all the interfacial drainage is due to pavement macrotexture.

By way of contrast, SN_{40}, measured using the ribbed tire as in ASTM Specification for Standard Tire for Pavement Resistance Tests (E 501) is a poor predictor of wet skidding accidents [2]. This is because the E 501 tire provides significant interfacial drainage caused by its grooves. An illustration of this is the fact that the traction of a surface measured with the E 501 tire is almost the same before and after longitudinal grooving, a modification that greatly improves wet traction as measured by the reduction in wet skidding accidents [4].

Based on the work of Horne et al. [7], the measure of skid resistance offered by the E 524 tire might be further improved by testing at light loads. They showed that footprint shape is a very important factor in hydroplaning. A broad, short footprint is adverse. Their work was specifically directed at understanding the source of wet pavement jackknifing accidents occurring with lightly loaded tractor trailers. Horne et al. have also shown that worn truck tires (low tread depth) can hydroplane in spite of high inflation pressures when tire loads are light (the tire footprint is broad and short).

The discussion thus far has centered on the sinkage zone and ways to assure that it is kept small through provision of proper interfacial drainage. This has clarified the importance of macrotexture.

In the remainder of the footprint, the draping and contact zones, microtexture is of paramount importance. In the draping zone the microtexture provides the high local pressures necessary to penetrate the remaining thin water film, thus beginning the development of frictional contact. In the contact zone microtexture excites the tread compound to generate frictional forces as previously discussed. Again, compromise is required because wear is also a function of microtexture [*3*].

Unfortunately, obtaining good macrotexture and microtexture in a new highway does not insure good traction throughout the life of the pavement. Pavement skid resistance changes with time [*2,3,4,8*]. Whitehurst and Neuhardt [*8*] present a comprehensive study of seasonal skid resistance variation for the reference surfaces at the Eastern Field Test Center located at the Ohio Transportation Research Center. These specially constructed surfaces have never been subjected to routine traffic. Yet their skid resistance varies with time in a seasonal manner. This proves that weathering changes pavement skid resistance.

Whitehurst and Neuhardt consider two pavements, PRS1 and PRS2, that can shed light on how to provide longer lasting skid resistance, a major concern of Wambold et al. [*4*]. PRS1 has exhibited long-term stability with only seasonal variation present. PRS4 has shown both a long-term decrease in skid resistance and a seasonal variation similar in magnitude to the seasonal variation shown by PRS1. The difference between the surfaces is that PRS1 was built of aggregates that do not polish easily and then given a tough, durable epoxy seal coat, which has kept the aggregate in place.

In the whole traction discussion macrotexture and microtexture have been central pavement features. They are crucial. But Lenke and Graul [*5*], who were concerned with the problem of deciding when to remove rubber buildup from runways in order to improve traction, made an important observation. Using current technology, skid resistance cannot be predicted well enough from texture measurements to eliminate the need for traction tests. There is an obvious need for research to make this prediction accurate enough that optical texture measurements like those mentioned by Wambold et al. can be fully utilized.

Wambold et al. raise a point that is a fitting conclusion to the discussion of traction. The wet skid resistance of accident sites is not different from the wet skid resistance of nearby control sites. They suggest that future research should concentrate on reliably identifying hazardous sites. Since this is the case, plainly more than the pavement skid resistance is involved in making a site hazardous. Can the difference between sites, which cannot be explained by skid resistance, be explained by a difference in traction demand caused by differences in road topography at each site? Could inclusion of vehicle dynamics in a systems approach to traction point out the relative risk at different locations with similar pavement skid numbers?

Wear

Pavement microtexture was just discussed as the pavement initiator of hysteretic and abrasive friction. Microtexture is the predominate pavement influence on tire wear. The symposium papers provide: a review of tire wear from a materials point of view [*3*], a look at typical stresses at the tire pavement interface [*9,10*], and an example application of interfacial stresses to the study of uneven tire wear [*11*]. The papers do not provide a general review of tire footprint mechanics, tire wear testing problems, vehicle influences on wear, or tire structural design effects.

Veith [*3*] begins his discussion of tire tread compound influences on wear by pointing out that the relationship among the wear rates of various tread compounds depends on pavement surface texture, traction demand (test severity), and how various tread materials interact with roadway materials. Indeed, abrasion is a three body system in which the road surface, road silt, and other contaminants, and the tread compound interact.

Tensile-tear rupture, fatigue, and chemical degradation of the tread compound all play significant parts in tread wear. Veith discusses all of these factors along with the characteristic chemical structure of the tread compound. Included in his discussion are the effect of polymer glass transition temperature, the nature of the reinforcement system (carbon black, and so forth), and the importance of ample amounts of anti-oxidants.

The influence of the factors Veith discusses combined with the nonconstant nature of the road surface [*8*] can produce great confusion for those testing tire tread wear. For example, it is not possible to study temperature effects using convoy tests without directly measuring microtexture since microtexture is seasonally variable [*3,8*].

The nonstationary character of the real world has also prevented laboratory abraders (devices for artifically determining the wear resistance of tread compounds) from achieving acceptable correlations to actual tire wear. However, laboratory abrasion experiments can provide a great deal of insight into wear mechanisms.

The kinematics of the rolling tire (a thick shell) on the pavement (a textured, semi-rigid half-space) produces complex three-dimensional stress distributions between the tire and the pavement. These stresses are associated with the abrasion that occurs in the tire pavement interface and can be used in the study of tire tread wear.

The interfacial stresses discussed in this STP were measured with three-dimensional force transducers (load pins) covered with a microtexture of the experimenter's choice [*9–11*]. For example, Lippmann [*9*] uses a square tipped transducer with a 5- by 5-mm tip coated with 80 grit abrasive paper.

Lippmann applied his transducer in slow rolling experiments with radial tires. Based on the results, he points out many of the general characteristics of the stress field between the tire and the road for an uncambered tire rolling straight ahead. A careful study of Lippmann's data will produce a good general understanding of the tire pavement interfacial stress field for the experimental conditions used. In examining this data set the reader should keep one point in mind. The shoulder lateral stress distribution discussed in this paper is not universally correct. Depending on tire design factors, the highest lateral and normal stresses may appear at the outside edge of the shoulder rib not at the inside as is the case in Lippmann's paper.

Howell and Perez [*10*] provide data on aircraft tire footprint forces. These data augment Lippmann's data and are a rare example of footprint force data for an aircraft tire.

Shepherd [*11*] applies footprint stress measurement to the study of diagonal wear, a particular form of uneven wear. He shows that uneven wear is a true systems problem by demonstrating the effects of small slip and camber angles that originate from suspension alignment. Even when various camber angles, slip angles, and combinations of the two lead to identical footprint shapes the resultant interfacial stresses differ because the combination of mechanisms differs for each slip and camber angle combination. In order to reach definite conclusions about wear Shepherd proposes a wear model denominated in terms of footprint stresses. This is a crucial step in using footprint stress data to study wear. Production of a confirmed and accurate wear model would be of great value to tire engineers.

The direction of the diagonals, high and low areas on the tread developed when diagonal wear occurs, is dependent on the sense of slip angle induced by a particular combination of rotation sense (left or right side of the car) and toe-in. Shepherd demonstrates that vibration of the tire/vehicle system plays a part in the repetition of diagonal wear around the tire. Thus, wear has a relation to tire pavement interaction noise, the final topic in this STP.

Noise and Vibration

Tire pavement interaction generated noise and vibration can originate from pavement texture, tire surface texture (tread pattern), or variations built into the tires. Pottinger et al. [*1*] provide an extensive review covering the effects of long wavelength pavement texture and macrotexture, tire uniformity, tire dynamics, vehicle dynamic response, human response, and five systems examples for in-the-vehicle noise and vibration. This paper does not cover moving load generated vibrations, environmental interactions, cargo damage, pavement fatigue, vehicle structural fatigue, or feedback paths external to the tire/vehicle system. The authors make the point that the system is paramountly important and should be taken into account by those working on ride and noise

McQuirt and Spangler [*12*] did extensive work on determination of pavement condition with respect to ride. They correlated jury ride opinions to Mays ride meter results and inertial profilometer results to jury opinions as to the need for nonroutine highway maintenance. The correlation of the Mays meter results with jury ratings varied with pavement type. The correlation of the inertial profilometer results with jury ratings of the need for nonroutine highway maintenance (re-surfacing) varied with road classification. These results are indicative of the variation in types of annoyance rated on different types of pavements, and the fact that human expectations vary in a complex way. This is in agreement with the information summarized in Pottinger et al. The inertial profilometer provides an excellent tool for deciding when nonroutine highway maintenance is required to improve ride.

Concluding Remarks

This STP provides a good general starting place for those interested in traction, wear, and tire pavement generated noise and vibration. Its particular strengths are diversity and a systems emphasis. It would be desirable to organize a follow-up symposium broadened to include the full systems concept envisioned in the beginning of this overview.

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