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Foreword

More than 30 states permit the use of studded tires, while some 18 states consider their use illegal. A major tire maker believes that studded tire sales represented 10 percent of the 13.7 million snow tires sold in the 1965-1966 winter season. Another market researcher estimated studded-tire sales at 2.7 million units, including 1.4 million recapped tires. A tungsten carbide stud manufacturer has estimated sales during the winter of 1965-66 at 225-250 million studs and estimates that in excess of half-a-billion studs will be sold during the 1966-1967 winter season.

These estimates imply wide-spread, popular acceptance of studded tires, yet pavement designers, maintenance engineers and safety conscious administrators have not been adequately informed regarding the influence of studded tires on pavement wear nor have they been informed on the safety aspects of studded tire usage. The seven papers published in this Record give insight into pavement wear attributed to the use of studded tires and the papers also report tests on stopping distances of vehicles equipped with studded tires on bare pavement and glare ice. Mention is made of stud retention in tires under different types and amounts of tire use.

The introductory paper describes tungsten carbide studs, their historical background and certain considerations governing placement of studs in winter tires.

One of the reports is concerned with investigations to determine whether studs increase skid resistance on ice and packed snow and if the studded tire is more slippery than plain treads on wet or dry pavements. A supplementary study of the traction of studded tires on dry concrete was done as a part of the work reported by Burke and McKenzie. The performance of studded tires on ice is reported in the form of an abridgment. The authors of these reports appear to be in general agreement that tungsten-carbide studded tires afford better stopping traction on ice but disagree on whether or not studded and unstudded tires provide the same amount of skid resistance on dry pavements.

Interpretation of test results varied among the authors who studied the abrasive effects of studded tires on highway pavement surfaces. On the basis of three reports, engineers might expect considerable damage on pavement areas subjected to large number of passages of vehicles equipped with studded tires. Two other reports evidence less concern although both authors recognized that additional testing would be necessary to determine whether or not significant abrasive damage might result from the passage of thousands of studded tires.

Studs were lost from tires during most of the series of tests reported and investigators indicated that a potential hazard was thereby created.

Contents

The Winter Tire Stud

W. P. MILLER,II, The Goodyear Tire & Rubber Company

A small unit, similar to a rivet, containing a tungsten carbide core is the latest development in winter driving safety. This device, called a winter tire stud, facilitates stopping, cornering, and starting on ice. With roughly 100 tire studs properly inserted into the tread pattern of a tire, favorable results can be achieved that were never before possible under icy conditions.

The European and Scandinavian countries are credited with the initial market exposure around 1959. Interest quickly spread, and by 1962 the major rubber companies in North America were taking steps to incorporate the winter studded tire as an active part of their program. Test markets were conducted during the 1963-1964 and 1964-1965 winter seasons with encouraging results. Considering the number of vehicles in Canada and the United States, marketing experts forecast its future potential would exceed by far that of Europe.

Now in its third year of marketing in North America, the studded tire has become a controversial product. There is still much to be determined concerning its effect on various road surfaces, and this information will help to resolve an extremely complex legal situation that has resulted. Several states and provinces have undertaken accelerated test programs to provide data, keeping in mind the safety aspect under winter conditions, which is the primary feature of the tire stud.

•APPROXIMATELY five years ago in Finland and Sweden, an old idea with a new concept began to make its mark on the driving public. This item consisted of a small piece of tungsten carbide, about the thickness of a ten-penny nail and roughly $^5/_{16}$ in. in length, encased in some variation of a jacket. As a unit, this device was called a winter tire stud. Since that time there have been many brand names attached to it, depending on the manufacturer.

The purpose of the tire stud is to serve as an antiskid device. It is designed to be an integral part of the tire tread, remaining there throughout its useful life. With approximately 100 studs per tire on the four wheels of a vehicle, cornering, stopping, and traction on ice and hard-packed snow are greatly improved.

WORKING PRINCIPLES

The center core of the unit is made of tungsten carbide (Fig. 1). Many years ago, similar traction devices were devised, tested, and used, but with little success. Because the rubber in the tire is inherently resistant to wear and under normal driving conditions will even outwear hardened steel, all previous attempts to develop antiskid devices were unsuccessful. This, however, was overcome with the use of tungsten carbide, one of the hardest man-made materials. Manufactured to the proper specifications, tungsten carbide closely matches the wear rate of the tread rubber under normal driving conditions.

Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

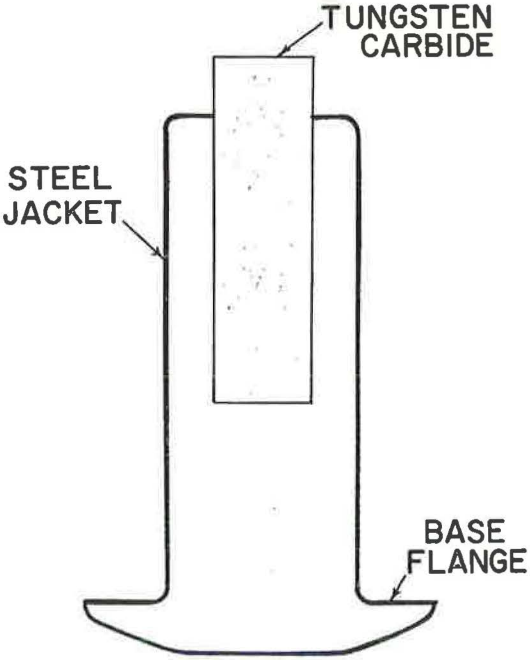

Figure 1. Tire stud.

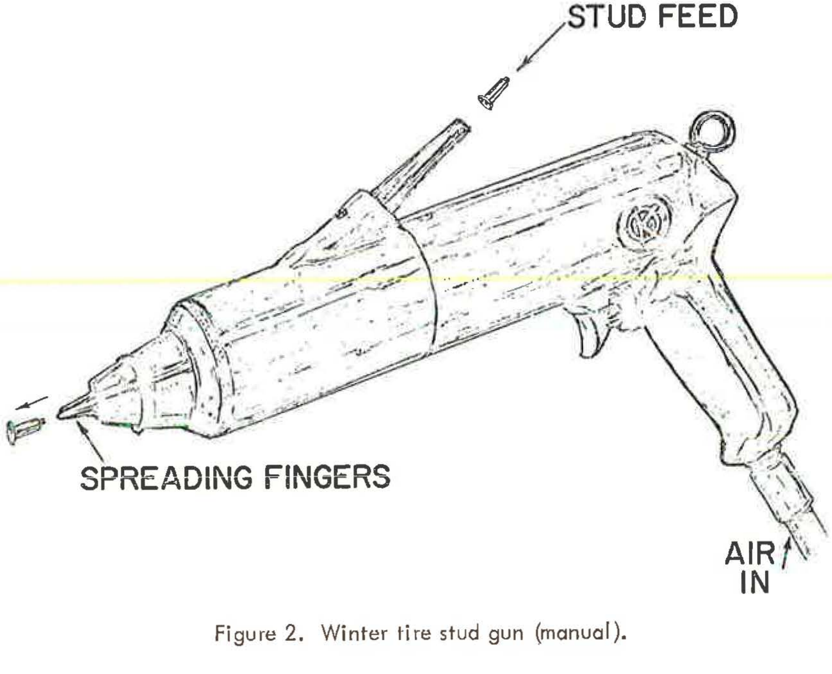

Figure 2. Winter tire stud gun (manual).

The carbide core is surrounded by a holding device known as the jacket. Jackets have been designed in various sizes and shapes and manufactured in as many different materials. These factors have significantly influenced marketing of the tire stud.

The particular jacket shown here consists of a low carbon steel, shaped to feature a large flange on the bottom portion of the unit. Other designs have used such materials as plastic, brass, aluminum and porcelain. Flanges on the body of the jacket have

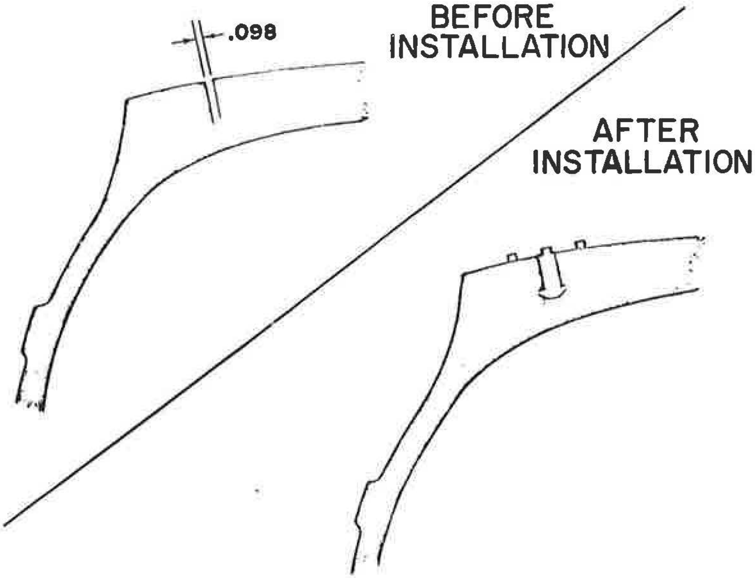

Figure 3. Tire before and after installation of stud.

numbered as high as four. One design even featured a threaded shank similar to a screw in place of the common flanged variety.

Regardless of the design, the working principle remains the same. The tire stud unit is fitted into the tread by means of a pressure operating gun (Fig. 2). The hole that receives the stud is very small, thereby causing high compressive forces to be exerted on all sides of the installed unit by the surrounding rubber (Fig. 3). This serves to hold it securely in place during normal service.

Once inserted, about 90 lb of force is required to pull the unit out of the tread. When the tire is traveling at 50 mph, the centrifugal force acting on the stud is less than 2 lb. It would require a speed of over 500 mph to create a centrifugal force great enough to eject the stud after it has been properly seated in the tire.

For maximum performance, the uppermost edge of the stud should protrude approximately $^{1}/_{16}$ in. beyond the tread surface of the tire. This protrusion provides the biting action into the ice for cornering, and stopping, and starting. As the tire wears down, the tungsten carbide shoud wear at an equal rate. Generally this is the case; however, wear is subject to many factors, such as driving habits and the driving conditions.

NUMBER OF STUDS REQUIRED

The number of tire studs used per tire has ranged from 50 to 500 or more. The latter, of course, represents an extreme situation, such as tires used for ice-racing.

Figure 4 shows a relationship of the coefficient of friction on ice vs the number of studs per tire (1).

Although the coefficient of friction continues to increase with the amount of studs per tire, there is a point at which this gain ceases to be economically justifiable. This point occurs at approximately 100 studs. The increase from 100 to 150 studs continues to produce a marked improvement; however, only special applications call for more than 150 studs.

Another important factor in considering the number of studs to use per tire is safety on wet, slippery surfaces. With approximately 100 studs in a tire, 98 percent of the contact area is rubber. This should be sufficient to provide the necessary traction under these conditions, especially in the front tires.

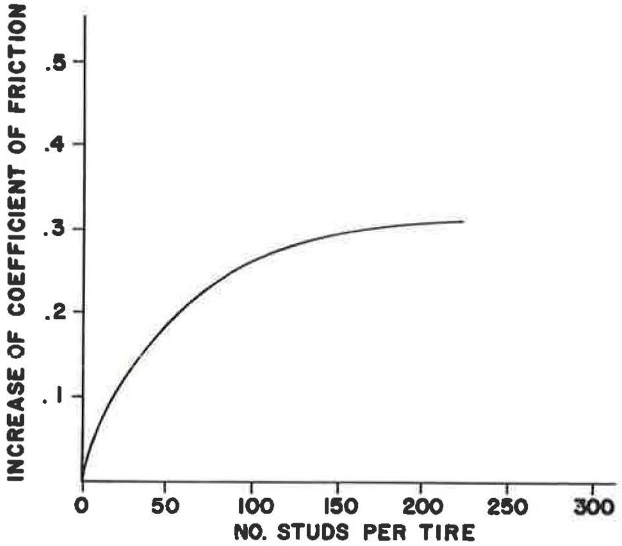

Figure 4. Approximate increase of coefficient of friction on icy road surface as function of number of studs per tire.

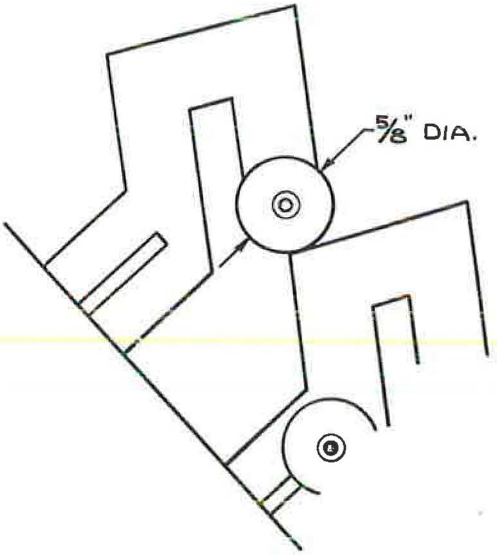

Figure 5. Tread designed for tire studs.

Maximum safety is achieved only when all four tires on the vehicle are equipped with tire studs. This permits maximum steering control and stopping traction not possible with rear-wheel installation only

PROPER INSTALLATION

Tire studs must be installed only in a tire that can meet the requirements necessary for maximum retention and safety. Not every tire qualifies, especially among the passenger tire sizes.

The area where the tire stud is to be installed should be free of any tread pattern within a $^5/_{16}$-in. radius of the insert (Fig. 5). This solid rubber portion provides a supporting element necessary to maintain maximum retention of the tire stud. New tire manufacturers and retreaders alike have converted their present equipment to obtain these supporting elements in the cured tire.

It is also necessary to maintain a minimum of $^3/_{32}$ in. of new rubber between the bottom flange of the tire stud and the top of the carcass (Fig. 6). In the case of retreaded tires, this distance is to the buff line. Because of the thickness of rubber gage necessary for proper stud installation, it is usually considered better to locate the studs closer to the shoulder of the tread rather than in the center region. Here, we have the maximum tread gages.

Most truck tires have the required portions of rubber in their normal tread pattern and would require no equipment alteration for the application of tire studs.

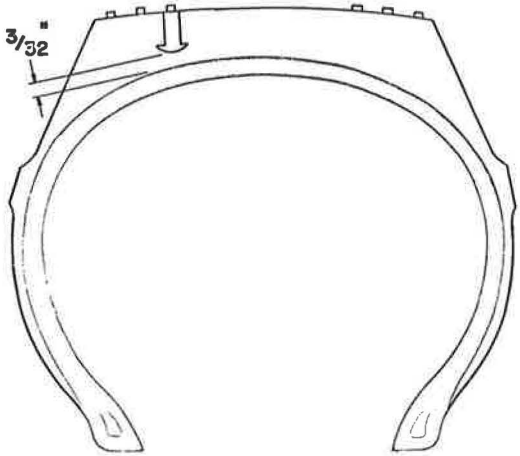

Figure 6. Studded tire with $^3/_{32}$ in. of new rubber between bottom flange of stud and top of carcass.

BACKGROUND

The modern studded tire achieved its first substantial consumer acceptance in the 1961-1962 winter season in Europe, principally in the Scandinavian countries. Such brand names as Keinas-Hokken, Kometa, and Secomet were among the first to be introduced. In Germany, one of the first tire studs introduced, and still the major one, was the Krupp-Widia.

Consumer acceptance of the tire stud in Europe was very encouraging during its first season. The safety aspect was extremely important. The speed of acceptance has been compared to the impact of the seat belt. In several Scandinavian countries it was reported that the studded tire consisted of as much as 50 percent of the winter tire market.

With the favorable results received in the European countries, it was only natural for various manufacturers to make their move to North America. There was without question a potential market for studded tires in North America many times greater than the existing market in Europe.

THE CANADIAN MARKET

The first real test market in Canada got under way during the 1963-1964 winter season (2). It is estimated that during that time approximately 1½ million tire studs were sold. During the following year promotion was increased and outlets were established throughout the provinces. The total number of tire studs marketed during that season was estimated at 6 million, an increase from the previous year of around 400 percent.

The various stud and tire manufacturers have now established complete programs in this field, and it is forecast that the final tally of tire studs marketed in Canada for the 1965-1966 winter season will be in excess of 25 million.

UNITED STATES MARKET

One of the first winter tire studs to be introduced in the United States was the Keinas-Hokken. This consisted of a bell-shaped plastic casing and a tungsten carbide insert. The major tire manufacturers did very little experimental work with this product. Probably one of the biggest problems at that time was the crude method used to insert the studs into the tire.

TABLE 1

STUDDED TIRE STATUS

Winter Season	No. Legal States	No. of States Marketed (legally)	No. of Tire Studs Sold in USA[a] (millions)	Approx. No. of Tires (100 studs/tire)
1963-1964	13	2-3	3-5	30,000
1964-1965	13	13	25-30	250,000
1965-1966	28	28	250-275+	2,500,000

[a] Estimate.

Soon after the brief life of the Keinas-Hokken came an improved version of the plastic-encased tire stud by a European manufacturer, the Scason Corporation. A revised method of inserting the stud was also a timely improvement. Several of the larger suppliers of both new and retread tires accepted the program and set up a limited test market for the 1963-1964 winter season.

As marketing plans got under way, information was revealed regarding the legality of this concept. A large number of states had a law on their books which in general read: "Any block, stud, flange, cleat or spike or any other protuberance of any material other than rubber which projects beyond the tread will be illegal...." This naturally dampened potential nationwide promotional plans.

In general, as a result of the legal situation, most of the 1963-1964 winter season test marketing was confined to two or three states. Because the winter tire was introduced into the market late in the year, very little was learned concerning the future market potential of this product. Speculation, however, ran high.

By spring of 1964, tire manufacturers had a large number of winter tire studs, of all sizes and shapes. They came from Sweden, Finland, England, Germany, Japan, and even the United States.

With the 1964-1965 winter season approaching, another attempt was made to determine the exact number of states in which the studded winter tire could be used legally. By midyear it appeared that the following thirteen states either did not prohibit the studded tire by law or had no existing laws for or against: New York, Massachusetts, Ohio, Missouri, Maine, Maryland, New Hampshire, Tennessee, Vermont, Nevada, Connecticut, Kentucky, and Oklahoma. It was later found that even this listing was inaccurate.

Table 1 briefly summarizes the past three winter seasons.

The United States was not the only country faced with this situation. During the same period, Canada was experiencing similar legal problems. Several of the provinces went along with the idea and others took a "wait-and-see" approach. The present situation remains somewhat unclear; however, most provinces are making temporary allowances to study the effect of tire studs on various road surfaces vs the safety aspect.

At the close of the 1964-1965 winter season, the activity among stud manufacturers and tire manufacturers (new and retread) was greatly increased. There was definite evidence that the studded winter tire was well accepted by the consumer. Many of the states were having a second look at their laws and taking steps either to amend them or allow for a temporary suspension to allow time to survey the situation. Several states established comprehensive test programs to study what effect, if any, this studded tire had on their road surfaces.

The 1965-1966 winter season is now completed and a substantial increase in the market prevailed. For the 1966-1967 winter season, forecasters look for the market to double.

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2. Merriman, J. Initial Impact of Tire Studs on the North American Scene. Toronto, Canada, Seco Studs Division of Fagersta Steels Ltd., July 8, 1965.

Performance of Studded Tires on Ice

A. H. EASTON, College of Engineering, University of Wisconsin

ABRIDGMENT

•THE RESULTS of tests of studded tires on ice in 1964 and 1965 by the National Safety Council Committee on Winter Driving Hazards left a number of questions unanswered. The 1966 tests will answer some of these questions; consequently, it was decided not to make a full report at this time but to wait until January 1967 when the 1966 test information could be included.

The average results of the tests through 1965 are given in the tables below.

SKID DISTANCE ON GLARE ICE AT 32 F[a]

Test Tires	Skid (ft)	
	New	Used[b]
Regular highway	167	188
Regular snow	167	174
Highway with studs	123	150
Snow tires with studs	125	152
Regular with reinforced chains	68	99[c]

[a] From 20 mph with all wheels locked, test tires on rear wheels, regular tires on front wheels.

[b] Used tires had been operated for 5,000 mi.

[c] Performance of new round chains which in some brands would closely simulate used reinforced chains.

TRACTION ON ICE

Test Tires	Rating	Improvement (%)
Regular highway	100	—
Regular snow	136	36
Snow tires with studs	236	136
Regular with reinforced chains	505	405

Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

Preliminary Studies of Effect of Studded Tires on Highway Pavements

P. A. JENSEN and G. R. KORFHAGE
Respectively, Research Engineer, and Research Project Engineer, Materials and Research Section, Minnesota Department of Highways

•DURING the early part of the 1964-1965 winter, pneumatic tires equipped with tungsten carbide studs embedded in the tread made their appearance in Minnesota. These tires were offered as a safety device to increase traction and reduce stopping distance of vehicles operating on icy streets and highways.

Under the Minnesota motor vehicle and traffic laws, adopted in 1927, these tires were ruled illegal for use. It was anticipated that efforts would be made in the 1965 session of the legislature to introduce legislation which would permit their use.

The increased safety factor afforded by these tires was not questioned or investigated in this study. Testing in Europe, where these tires have gained wide acceptance in recent years, and in the United States has effectively demonstrated their safety features. Of primary concern was the possible damage which might be done to pavement surfaces if these tires were to gain widespread acceptance. Inquiries to several state highway departments, the U. S. Bureau of Public Roads, the Highway Research Board and representatives of the tire industry revealed that a difference of opinion existed regarding the degree and the extent of abrasive damage to pavements that might result through their use. Little or no factual information existed on this question. It was evident that such information would have to be gained to answer questions expected from the legislature.

This preliminary study was undertaken to determine the amount of damage which might be done to highway pavements by vehicles equipped with studded tires. It was decided that the most damage could be expected in areas where vehicles were braking or accelerating. It was further decided to limit testing to dry pavement surfaces since in this condition they would be most subject to the abrasive action of the studs.

A test course was set up on a section of Interstate highway not yet opened to traffic. At this site two types of pavement were available for testing; portland cement concrete pavement and a plant-mixed bituminous pavement commonly used on Minnesota highways and urban streets for moderate traffic.

Automobile tires equipped with tungsten carbide studs were tested in a series of starts and stops on both types of pavement. Normal stops and starts were made to simulate traffic conditions which could be expected at a typical urban intersection. To simulate the most severe abrasive damage that a pavement surface would be subjected to, panic stops (wheels locked and sliding) from 20 mph and rapid starts (acceleration from a stopped position with rear wheels spinning) were made on both types of pavement.

It was hoped that this study would also provide information on the possibility of loss of the studs from the tires and the potential hazard to following traffic.

Because of time limitations, it was desired to obtain as quickly as possible some general information on the possible damaging effects of studded tires, and consequently no provisions were made to get quantitative measurements of the pavement wear. The results obtained were therefore qualitative. Photographs were obtained to record visual evidence of pavement damage.

Paper sponsored by the Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

Figure 1. Studded conventional-tread tire.

Figure 2. Studded snow-tread tire.

Only 310 repetitions of each traffic application were made. On the basis of this limited testing, it was concluded: (a) that widespread use of studded tires can be expected to cause some abrasive damage to pavement surfaces, (b) that the most severe damage would occur at locations of stopping and starting traffic, and (c) that bituminous pavements would be subject to more damage than portland cement concrete under similar conditions. It was recognized that additional testing would be necessary to determine whether significant abrasive damage might result from constant speed traffic.

EXPERIMENTAL PROCEDURE

Initially, 14 test sections were established on a ½-mi section of the selected highway. The same tests were made on each of two types of pavement, the portland cement concrete main roadway and the bituminous pavement on the right shoulder.

As originally planned, on each type of surface one section was designated for normal starts, one for normal stops, one for rapid starts and one for panic stops from each of four different speeds, 10, 20, 30 and 50 mph. The normal starts were made from a stopped position, accelerating to 30 mph in the shortest possible distance without spinning the rear wheels. Normal stops were made by braking from 30 mph to a complete stop without locking or sliding the wheels. Rapid starts were made from a stopped position using full power to deliberately spin the rear wheels. Panic stops were made with the wheels locked, the vehicle coming to a complete stop with all four wheels sliding.

After completing 21 applications of each test the tires showed signs of severe wear. The amount of damage that each type of pavement had sustained at this point appeared about equal for the four panic stop tests. Only the length of the damaged area varied with speed. It was, therefore, decided to discontinue the panic stops from speeds of 10, 30 and 50 mph and continue only those at 20 mph.

Testing began in January 1965 and continued through March. Ambient temperatures were generally in the range from 40 to -10 F. All tests were made when the pavement surfaces were free of ice and snow. A total of 310 applications of traffic were applied to each of the four test sections on each type of pavement.

The testing was done with a 1962 Plymouth sedan, equipped with four studded tires. On the front were two conventional-tread tires containing 80 tungsten carbide studs per tire (Fig. 1). On the rear were two snow-tread tires containing 130 tungsten carbide studs per tire (Fig. 2). The tires were inflated to a pressure of 32 lb when cold. A description of the studs, their installation in the tires, and their performance under the conditions of these tests is included in the appendix.

TEST RESULTS

Tests on Portland Cement Concrete Pavement

Normal Stops.—The location of the test section where normal stops were made on the concrete pavement is shown in Figure 3. The white bar in the picture indicates the location of a hypothetical stop sign. The vehicle approached this section at 30 mph, traveling in the direction indicated by the arrow and braked to a complete stop at the white bar. The surface condition of the concrete pavement after 210 normal stops is shown in Figure 4. There was little or no apparent difference in the surface condition of the pavement in the wheelpath (area to the left of pencil in Fig. 4) and the untested concrete pavement (area to the right of pencil). The dark spots evident on the pavement surface in this picture are oxidized residues from snow plow blades. There was no visible change in the condition of the concrete surface after 310 normal stops.

Normal Starts.—After the vehicle had completed a normal stop at the location shown in Figure 3, a normal start was made. The condition of the pavement surface after 310 normal starts was similar to that of the section where the normal stops were made. Although the studs left visible short, scratch-like marks on the concrete in both test sections, there was no apparent abrasive loss of the concrete surface.

Panic Stops.—At the beginning of this study, panic stops were made from speeds of 10, 20, 30 and 50 mph. Figure 5 shows the concrete surface after a single panic stop from 30 mph at a location where no other tests had been made. The skid marks and the scratches left by the studs are visible in the foreground.

There was no apparent difference in the damage to the concrete surface after 21 applications of each of the four different speeds. The different speeds only affected the length of the damaged area. Because the tires were wearing down rapidly, it was decided to discontinue the panic stops from 10, 30 and 50 mph.

Figure 6 shows the condition of the concrete surface after 310 panic stops had been made from a speed of 20 mph. The wheelpath is shown on the left in the picture and the

Figure 3. Location of normal stopping and starting tests on concrete.

Figure 4. Surface of concrete after 210 normal stops.

Figure 5. Concrete surface after single panic stop.

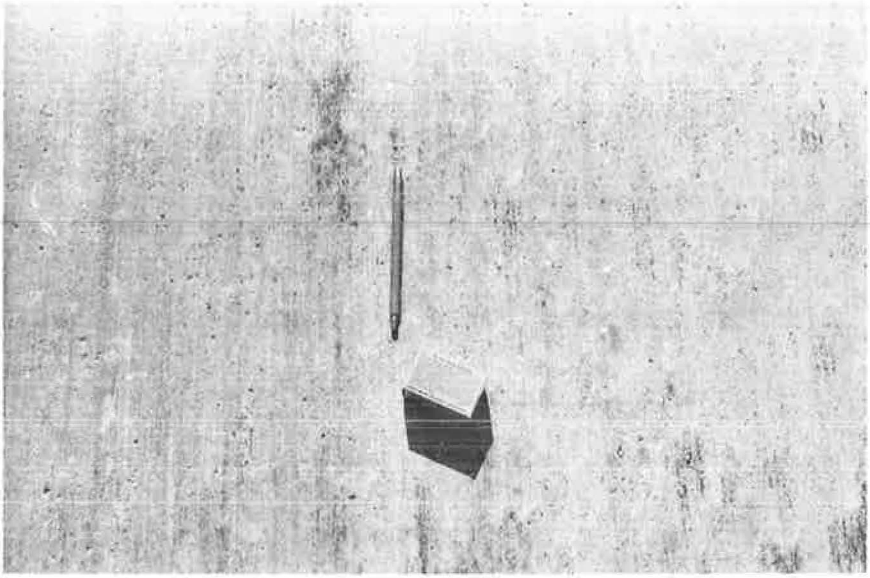

Figure 6. Surface of concrete after 310 panic stops.

untested surface on the right. The concrete had become quite polished in the wheelpath but the abrasion was limited to loss of the surface finish produced by the burlap drag. There was no measurable amount of rutting evident when a straightedge was laid across the wheelpath.

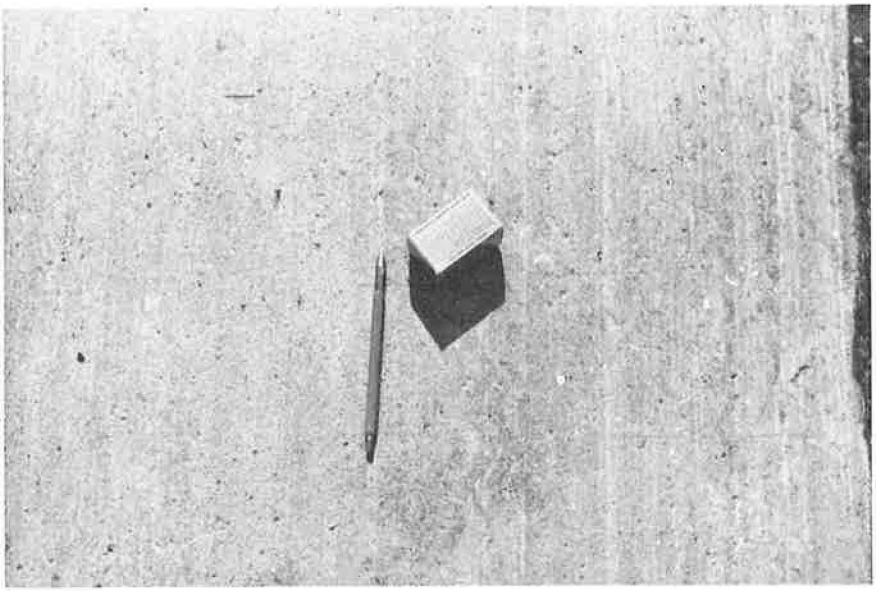

Figure 7. Surface of concrete after 310 rapid starts.

Figure 8. Surface of bituminous pavement after 210 normal stops.

Rapid Starts.—Rapid starts had about the same effect on the concrete as did the panic stops. The surface became quite polished and the burlap drag surface finish was lost. There was no measurable rutting. The condition of the concrete surface after 310 rapid starts is shown in Figure 7. The wheelpath is on the right in this picture.

Figure 9. Bituminous surface after 210 panic stops.

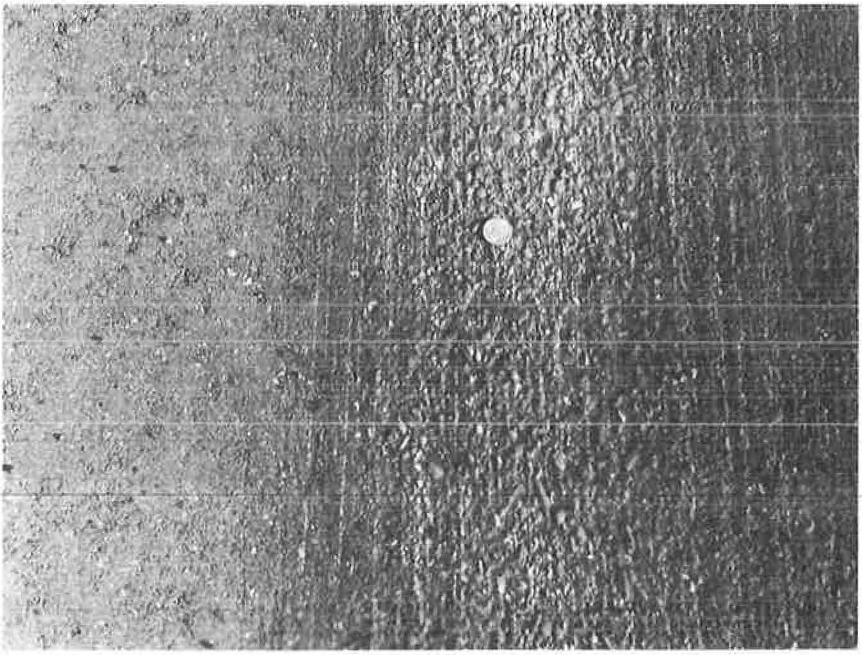

Figure 10. Bituminous surface after 210 panic stops.

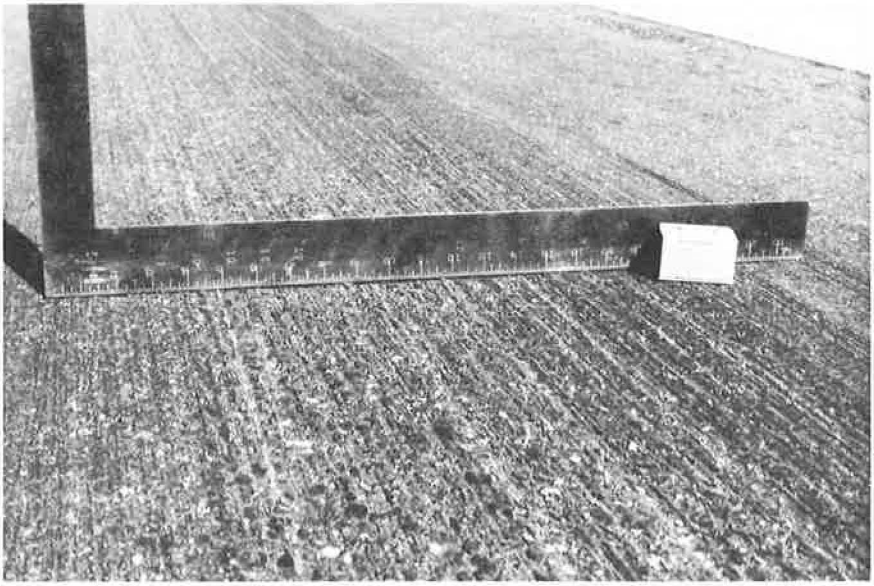

Figure 11. Bituminous surface after 310 panic stops.

Tests on Bituminous Pavement

Normal Stops. —No significant damage was done to the bituminous surface after 310 normal stops, although the first signs of some surface abrasion were beginning to appear. In Figure 8, little difference can be detected between the condition of the surface in the wheelpath (covered by the carpenter's square) and the untested surface to the left, but there is a difference in surface texture of the untested surface to the right of the wheelpath. The carpenter's square, placed across the wheelpath, shows that no rutting occurred.

Normal Starts. —Normal starts were made following each normal stop. After 310 repetitions the condition of the pavement surface was the same as that described for the normal stops.

Panic Stops. —The bituminous pavement was significantly damaged from repetitions of panic stops. The damage progressed from single gouges produced by each of the four rows of studs in each tire to severely abraded wheelpaths. Figures 9 through 12 show the condition of the bituminous surface after 210 and 310 panic stops from a speed of 20 mph. The abrasive damage was principally loss of fine aggregate and bitumen from between the coarse aggregate particles leaving a very rough, open-textured surface. There was little, if any, actual rutting (Fig. 12). Many of the coarse aggregate particles are still touching the straightedge.

Rapid Starts. —There was a significant amount of damage to the bituminous pavement from repetitions of panic starts. The damage started and progressed similarly to that produced by the panic stops. Figures 13 and 14 show the condition of the bituminous surface after 210 and 310 rapid starts, respectively. In Figure 13 the pencil is lying in the wheelpath where most of the repetitions were made. To the left of this main wheelpath is an area where only a few rapid starts were made. The damage to the surface from this test was very similar to the damage done in the panic stop tests. Although in Figure 14 it appears that some very shallow rutting has occurred, this is not positive, since it is not known whether the surface was a true plane at this location before testing started.

Performance of Studs

A question often raised in regard to the use of studded tires is the possible loss of studs from tires of vehicles traveling at high speeds. It has been suggested that a

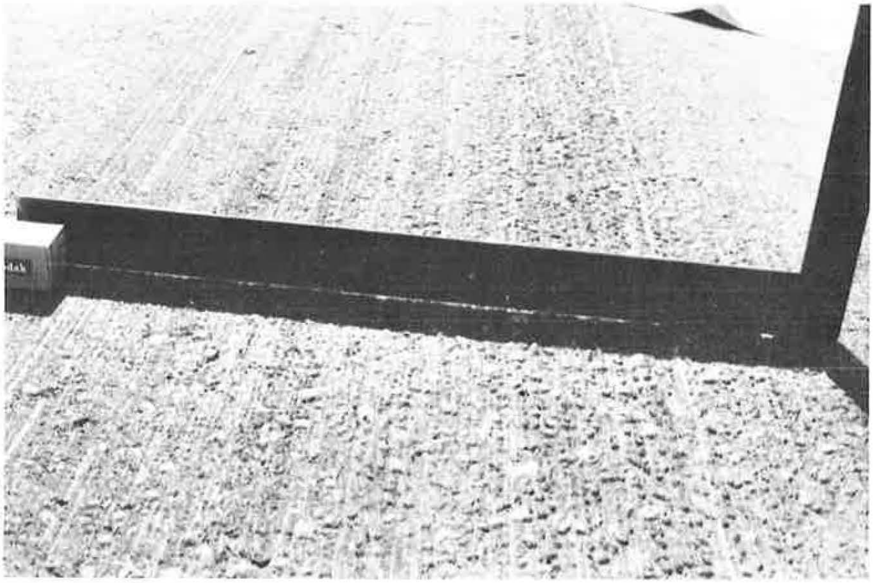

Figure 12. Bituminous surface after 310 panic stops.

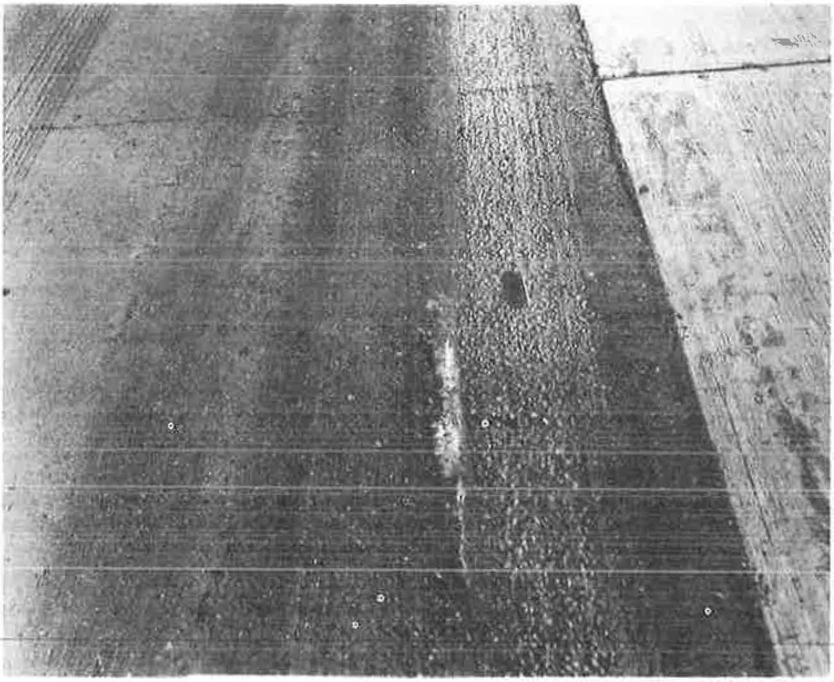

Figure 13. Bituminous surface after 210 rapid starts.

stud thrown from a tire could be a potential hazard, particularly to vehicles following closely behind. It was hoped that the study might also provide some indication of the probability of the studs being thrown out.

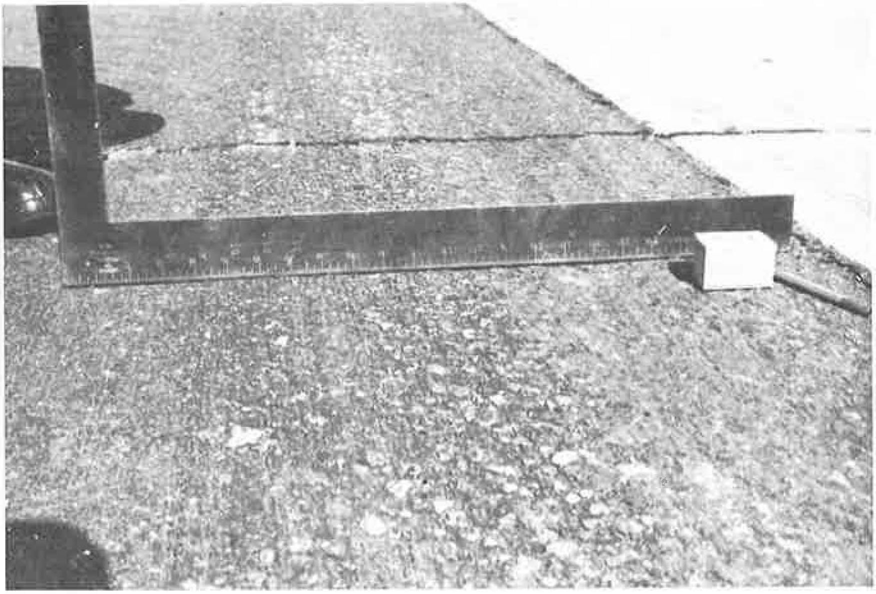

Figure 14. Bituminous surface after 310 rapid starts.

Figure 15. Condition of bituminous surface at typical intersection.

Shortly after the tests were started, it became evident that the tires and the studs were being subjected to abnormally severe wear. Some studs were being lost from the tires (see Appendix), but this loss could not, in all fairness, be compared to the loss which might occur under normal vehicle operating conditions.

During the middle of the winter, a pair of new studded snow tires was mounted on a second passenger car. This vehicle was used routinely by highway department personnel for both urban and rural highway travel. Each of the snow tires was equipped with 63 tungsten carbide studs. Periodic observations and measurements were made to determine performance of the studs and tires under normal vehicle operating conditions.

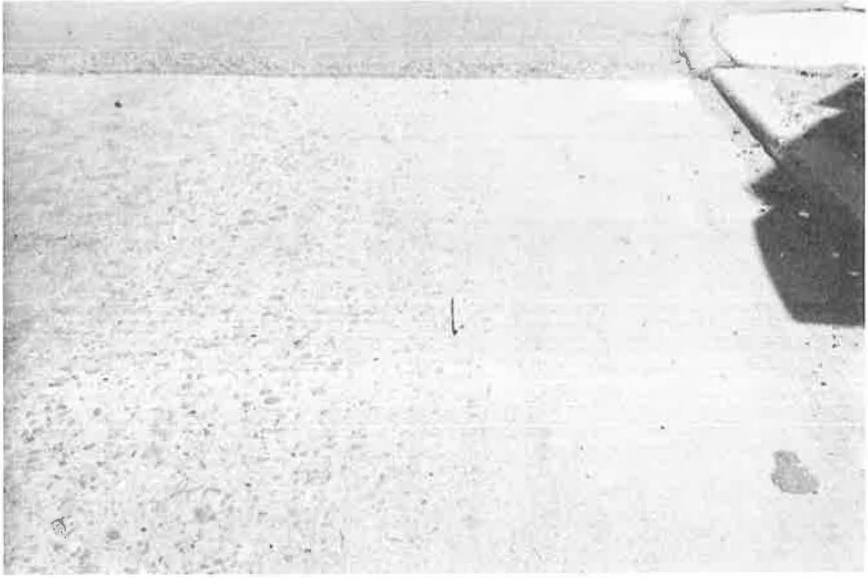

Figure 16. Condition of concrete surface at a high volume intersection.

When these tires were removed late in April, they had been driven nearly 5000 miles. The general condition of the studs and the tires was good, except that a few of the studs showed considerable wear. None of the studs was lost from the tires.

Information supplied by the manufacturers indicates that the tire tread and the tungsten carbide studs are designed to wear at the same rate. After 5000 mi of normal driving, the average tread wear was 0.06 in. and the average stud wear was 0.09 in. This suggests that, at least for this brand of tires and studs, under normal vehicle operation the tungsten carbide studs would wear at a slightly faster rate than the tires themselves, at least during the early life of the tire when there might be some stud protrusion.

SUMMARY

After a total of 310 applications of a series of normal and emergency stops and starts, the following conditions existed:

1. Both portland cement concrete and bituminous pavement surface subjected to normal stops and starts were in substantially the same condition as they were before the tests.
2. The portland cement concrete pavement subjected to panic stops and rapid starts lost the surface finish produced by the burlap drag, and became quite polished, but there was no discernible rutting.
3. The bituminous pavement subjected to panic stops and rapid starts was damaged significantly. There was an appreciable loss of fine aggregate and bitumen from the surface. However, there was little if any loss of the coarse aggregate particles.
4. There was evidence of loss of studs from the tires subjected to abnormal abuse and wear. Tires subjected to 5000 miles of normal travel retained the studs.

DISCUSSION AND RECOMMENDATIONS

From the limited testing, it is not possible to draw definite conclusions on the extent or severity of abrasive damage which might be done by normal highway traffic using studded tires. The tests suggest that damage to bituminous pavements may be expected at locations where there are frequent stops and starts. It seems probable that wide acceptance and use of studded tires would necessitate some additional maintenance at signalized or controlled stop intersections. The extent of damage would probably not be so great as to make the required maintenance or repair an impossible task. These localized areas could undoubtedly be restored or repaired using regular or, if necessary, special maintenance techniques and materials.

Abrasive damage at controlled intersections is not a new problem. Damage to pavements has long been evident, particularly at intersections, from the abrasive action of normal traffic and sand commonly used in winter maintenance. Figure 15 shows the condition of a 7-yr-old bituminous pavement at a typical signalized urban intersection. The damage at this location is not unlike that which was done by the studded tires in the panic stop and rapid start tests. Figure 16 shows the abrasive damage that a 10-yr old concrete pavement has sustained at a typical high traffic volume urban intersection.

Of greater concern would be the damage which might result from widespread use of studded tires through a large number of repetitions of normal traffic. If abrasive damage should occur as a result of normal, constant-speed traffic, the extent of this damage might cover a large portion of highway surfaces and would present a maintenance problem of major proportions. The limited preliminary testing did not show visual evidence of damage from constant-speed traffic.

On the basis of the tests conducted, it was decided that there was not enough evidence that serious widespread pavement damage would result through the use of studded tires to withhold from the traveling public the potential safety benefits they would provide. The 1965 Minnesota legislature revised the law to permit the use of studded tires during the winter months (October 15 through April 15) on a limited trial basis. It was recognized that factual information on the abrasive action of these tires was limited and additional data must be obtained. The legislation was, therefore, restricted to a 2-yr trial period during which time additional tests could be conducted and observations made on pavements exposed to use by normal traffic. Other possible disadvantages might also be brought to light during this trial period. The law will then be subject to reconsideration.

To evaluate further the possible abrasive damage of studded tires, plans were made by the Minnesota Highway Department to conduct additional controlled tests. To be included in the study are a large number of repetitions of constant-speed traffic and normal starts and stops on both concrete and bituminous pavements and on two types of seal coats applied to the bituminous pavement surface. Quantitative measurements will be made to determine the rate of wear on these surfaces. It is hoped that this will permit a prediction of service life and need for restoration or repair.

Appendix

The studs in the tires used in this study were of two types: one having the tungsten carbide core encased in plastic, and the other encased in steel.

Tungsten Carbide Cores

The heart of the studs is the core, made of tungsten carbide which has qualities of unusual hardness and toughness. The core is about $\frac{1}{8}$ in. in diameter and about $\frac{3}{8}$ in. long. Most of its length is encased either in plastic or metal (either steel or aluminum) leaving about $\frac{1}{16}$ in. of core projecting from the encasement.

Plastic Encasement

The plastic used for the studs is a relatively hard, tough material which apparently does not become soft at the higher operating temperatures nor does it become brittle at low winter temperatures. The length of the plastic type studs used in this experiment was about $\frac{5}{8}$ in. overall. The diameter over most of its length is about $\frac{1}{4}$ in. A cross-section view of a stud having a plastic encasement is shown in Figure 17.

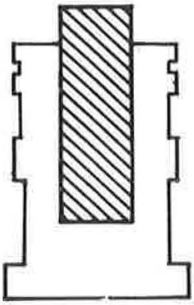

Figure 17. Cross-section of plastic encasement type stud, scale approximately 3X actual size.

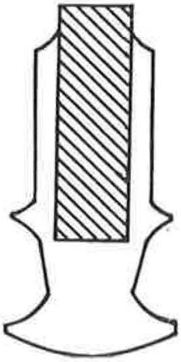

Figure 18. Cross-section of steel encasement type stud, scale approximately 3X actual size.

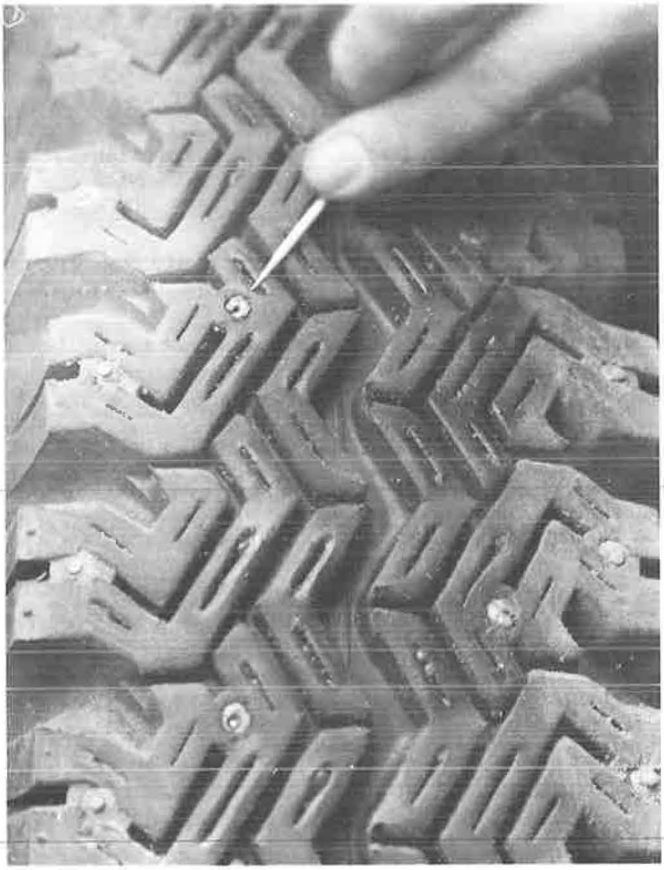

Figure 19. Condition of plastic encasement type studs after 21 series of stops and starts.

Steel Encasement

The overall length of the metal-encased studs used in the front tires during this experiment was about $^1/_2$ in. The upper half of the stud (the end nearest the tire surface) has a diameter of $^3/_{16}$ in. A cross-section view of one of these studs is shown in Figure 18. The studs used in the left rear tire were similar to those used in the front tires.

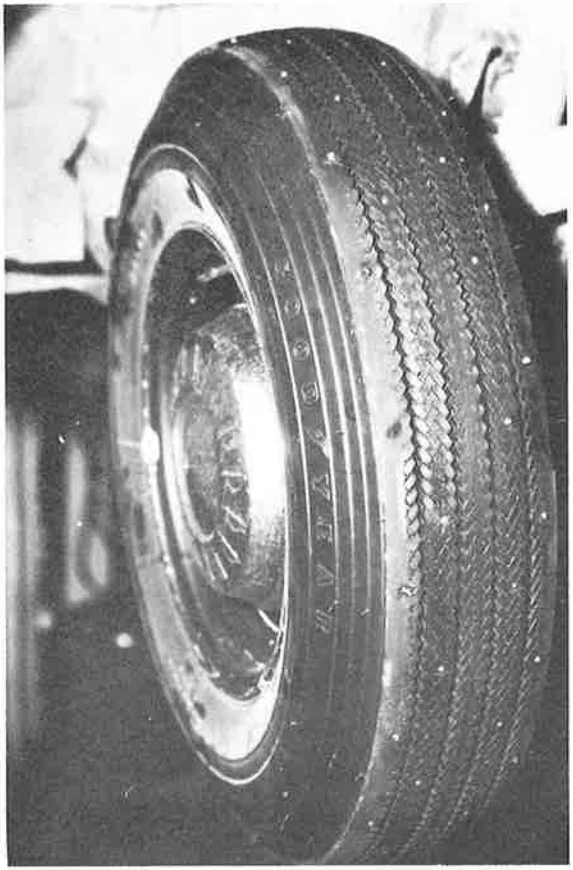

Figure 20. Condition of steel encasement type studs after 21 series of stops and starts.

Installation of Studs in Tires

The studs were inserted into holes in the tires by an air pressure gun. These holes, which were approximately $^1/_8$ in. in diameter by $^1/_2$ in. in depth, were molded in the tires during manufacture.

Each front tire on the vehicle used in this study contained four rows of 20 studs each or a total of 80 studs. The circumferential spacing of the studs was about 3 in. Each rear tire had four rows of studs also, but the two outer rows had provisions for 44 studs each and the two inner rows 22 studs. Since two studs were missing from each rear tire, they both had a total of 130. The circumferential spacing varied from $2^1/_8$ to $3^5/_{16}$ in. in the inner rows and from $1^3/_{16}$ to $1^{11}/_{16}$ in. in the outer. In both the front and rear tires, the inner rows were about 2 in. apart and the outer rows were 1 in. from the inner rows.

Performance of Studs

Plastic Encasement Type.—After 21 series of stops and starts (168 panic stops from various speeds and 63 rapid starts), a total of five cores was missing from the right rear tire (the tire on which plastic encasement type studs were used). All of these were from the inner two rows. In some cases, only the tungsten carbide core was missing, but in other cases, the plastic encasement was gone also. A number of other cores were thrust part way through the side wall of the plastic encasement. The cores which were not missing had rounded-off edges but were still in fair condition. At this

Figure 21. Wear on front tires after 21 series of stops and starts (400 mi total travel).

time, these tires had been driven less than 400 miles. However, it must be remembered that during this period the tires were subjected to much more severe use than would be encountered in normal driving. Figure 19 shows the condition of some of the plastic encasement type studs.

After 210 repetitions at each test site, 28 cores were missing, all but two of them from the two inner rows. In most cases, the encasement was still in the tire, but the core was missing. The studs which remained in the tire appeared to be well worn. At this time, the car had been driven about 800 miles since the studded tires had been mounted on it.

Shortly after completion of the first 210 repetitions, the car was driven at a speed of 70 mph for an aggregate of 100 miles. Surveys of the studs before and after this trip revealed that six cores had been thrown out. However, these studs were undoubtedly loosened during the repeated abnormal panic stops and rapid starts made before this time.

After 310 repetitions, 96 cores (74%) were missing, this number including all the cores from the inner two rows. Those in the two outer rows which remained appeared to be well worn. Since the beginning of the tests, the vehicle on which the tires were mounted had been driven about 3,300 miles, a major portion of this being at rural highway speeds.

Steel Encasement Type.—No studs or cores were missing from the right front or left rear tire after 21 repetitions of stopping and starting at each test site. However, one stud had been lost from the left front tire. A number of cores, especially those in the outer rows of the front tires, had developed a sharp point. Most of the other studs appeared to be in good condition. Figure 20 shows the condition of the studs in the left front tire. The outside edges of the front tires had worn down about $\frac{1}{4}$ to $\frac{3}{8}$ in. during this short period (Fig. 21).

After 210 repetitions, one additional stud had been lost from each of the front tires. Most of the studs in the two outer rows were in very poor condition. They had become quite pointed and many had been tilted from their original position. The studs in the inner rows of the front tires and in the left rear tire showed wear, but were in fair to good condition. During the high speed trip mentioned earlier, no steel encasement type studs were thrown out.

No cores were missing from the left rear tire after the entire 310 repetitions had been made. However, all the cores seemed to be well worn. The left front and right front tires had 16 and 27 cores missing, respectively. Two of the cores had broken off, leaving the encasement in the tire. In all other cases, the entire stud was missing. The cores in the front tires were not worn nearly as much as those in the left rear tire, but the points which had developed on them earlier had been worn off. Many of the studs in the outer rows were tilted from their original position and appeared to be working loose.

Studded Tires—Skid Resistance and Pavement Damage

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Studded snow tires were introduced by tire manufacturers in 1964 to provide increased skid resistance and traction on ice and packed snow. A typical stud consists of a $^{3}/_{32}$-in. diameter tungsten carbide core protruding $^{1}/_{16}$ in. from a $^{3}/_{16}$-in. diameter steel sheath which fits very tightly in holes formed in the tread.

This investigation was performed to determine if studded tires would be more slippery than regular snow treads on wet or dry pavements, and to examine the effect of studs on skid resistance on ice and packed snow. In addition, information was desired concerning pavement damage which might be caused by studded tires.

A studded snow tire and an identical snow tire without studs were purchased. The tires (7.75 × 14) were made by a major manufacturer, and one contained about 70 studs, 6 of which contacted the road surface at any one time. These tires were mounted on the department skid test trailer. Tests were performed by locking a trailer wheel and sliding the test tire at a constant speed of 30 mph. Over 100 tests were performed with the studded tire on ice and snow and on wet and dry bituminous and concrete pavements. After each test the road surface was examined for damage.

The studded and unstudded tires provided approximately the same amount of skid resistance on bare pavements, either wet or dry, at 30 mph. At this speed the studded tire increased skid resistance on ice about 40 percent and on packed snow about 9 percent. The pavement damage caused by the sliding studded tire was not considered significant. However, it was not possible to obtain an indication of pavement wear that might result from extensive use of studded tires on highways carrying large volumes of traffic.

•THE TERM skidding, as applied to motor vehicles, is usually defined as the application of the brakes sufficient to slide one or more wheels over the pavement with little or no rotation. Skidding is a factor in many serious accidents, especially when the road surface is wet or covered by ice or snow. In Great Britain almost 9 percent of all highway accidents in 1957 involved skidding on wet or icy pavements (1). In Virginia, 5 percent of all accidents between 1953 and 1958 were caused by skidding (2).

In 1960, the New York State Department of Public Works Bureau of Physical Research initiated an investigation of the skid resistance of highway pavements. Following the construction of a two-wheel drag force type trailer, numerous locked wheel skid

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Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

tests were performed on various road surfaces (3). With the exception of bleeding asphalt, clean dry pavements exhibit very good skid resistance. When wet, however, some surfaces become slippery and skidding is more likely to occur. The presence of ice or packed snow further increases the skidding hazard.

To obtain increased traction on slippery surfaces, many special tread designs have been produced. The normal passenger car tire has angled ribs cut to increase the number of lateral edges in the tire tread. These edges provide a wiping action which removes the lubricating water from between the road and tire, thus increasing the skid resistance. Tires designed to increase traction in snow are characterized by deep grooves which entrap snow and thus dig into snow-covered surfaces (4).

For the past three years European tire manufacturers have been selling snow tires with tungsten carbide studs imbedded in the tread surface. Last year the studded tire was introduced in the United States. The studs, which protrude about $^1/_{16}$ in. above the tread surface, dig into ice or hard-packed snow. This mechanical interlocking results in increased skid resistance on these surfaces. There was concern, however, that on bare pavement the studs might "skate" over the surface and cause decreased friction, or that the studded tire might accelerate pavement wear or cause extensive surface damage by dislodging aggregate particles when vehicles brake, corner, or accelerate.

This investigation was undertaken to (a) determine the ability of tungsten carbide studs to increase skid resistance of a snow tire on ice and packed snow; (b) determine the effect of studs on the frictional coefficient when there is no snow or ice on the pavement; and (c) investigate the extent of pavement damage caused by a studded tire sliding along bare pavement.

INVESTIGATION

Measuring Equipment

All tests were performed with the New York State Department of Public Works skid trailer (Fig. 1). The effective coefficient of friction between tire and pavement was measured in the following manner. The skid truck was accelerated to a predetermined speed and a sequence timer was switched on when the test section was reached. The timer activated a recorder and water pump and applied brakes which locked the left wheel of the trailer. After a 1.8-sec skid, the brakes were released and the pump and recorder were shut off by the timer. During all skids, a constant speed of 30 mph was maintained by the truck driver.

When the test wheel locked, the drag force between tire and pavement was transmitted through the axle, the leaf springs and the drag links to aluminum bending beams. The strain in the bending beams was sensed by electrical resistance strain gages and recorded on paper tape. These strain readings, which were proportional to the drag force, were converted to effective coefficient of pavement friction by use of a calibration curve.

Tires

Tests were performed with two 7.75 × 14 snow tires of the same tread design and composition, one containing 67 tungsten carbide studs and the other none. As a check, wetted pavements were also tested with a 7.50 × 14 ASTM standard pavement test tire. Figure 2 shows the tread patterns of these three tires.

The studded tire used in these tests is typical of those currently available commercially. The studs are forced into small holes in the tire tread, and consequently held firmly in place. A stud consists of a tungsten carbide center ($^3/_{32}$ in. diameter) which protrudes about $^1/_{16}$ in. above a steel sheath. The sheath is approximately $^3/_{16}$ in. in diameter at the tread surface and is contoured to hold firmly in the tread rubber. The entire assembly is about $^1/_2$ in. long (Fig. 3).

The tungsten carbide centers of the 67 studs occupied only 0.10 percent of the nominal tread area (circumference times width). The area occupied by the total stud, including the sheath, was 0.43 percent of the nominal tread area.

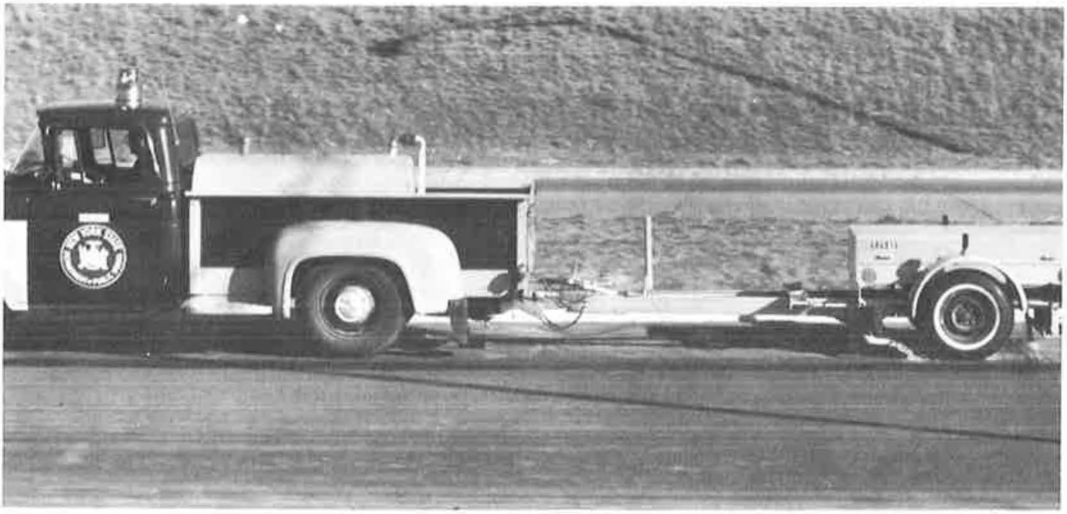

Figure 1. Skid trailer.

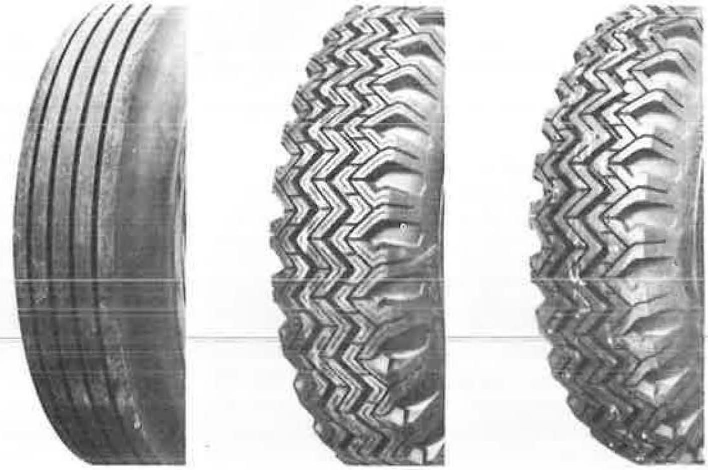

Figure 2. Test tire treads.

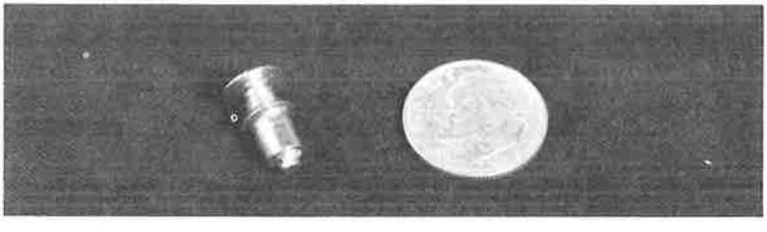

Figure 3. Tungsten carbide stud.

TABLE 1

SKID TEST RESULTS

Surface Type	Avg. Coeff. of Friction			Increase in Traction Due to Studs (%)
	ASTM Tire	Snow Tire	Studded Tire	
Ice				
Below 20 F		0.21	0.29	38
Above 30 F		0.10	0.14	40
Packed snow		0.35	0.38	9
Old concrete				
Dry		0.70	0.71	1
Wet	0.35	0.29	0.30	3
New concrete				
Dry		0.71	0.71	0
Wet	0.56	0.52	0.54	4
Old bituminous				
Dry		0.67	0.68	1
Wet	0.34	0.29	0.30	3
New bituminous				
Dry		0.69	0.70	1
Wet	0.59	0.56	0.58	4

Pavement Surfaces

New and old bituminous and concrete pavements were tested both wet and dry. The older surfaces had been highly polished by traffic. When tests were performed on wetted pavements, water was supplied in front of the sliding tire from a tank on the truck which towed the skid trailer.

For the dry pavement tests, the water pump was disconnected and the skid was shortened to ½ sec (25 ft in length) to prevent excessive tire damage.

Ice was also classified as wet or dry, but no water was applied by the watering system. When the air temperature rose above 30 F, ice was considered wet; when it was below 20 F, the ice was classified as dry.

The snow tested was packed, but the 1000-lb wheel load of the skid trailer was sufficient to cause the rubber blocks of the snow tire treads to "dig in."

RESULTS

The results of the skid tests performed at 30 mph with the two snow tires and the ASTM tire are given in Table 1. To reduce the influence of surface variability on the test results, the coefficient of friction values are averages of four to seven individual skid tests. The results obtained with the regular snow tire are compared to those obtained with the snow tire containing tungsten carbide studs. This table also gives the percent increases in skid resistance attributed to the studs in the snow tire so equipped.

These test data show that on ice there is an improvement in skid resistance due to the studs. On wet ice, the effective coefficient of friction was 0.10 with the snow tire and 0.14 with the studded tire. On dry ice, the coefficient increased from 0.21 to 0.29 with the addition of the studs. These values represent about a 40 percent increase in skid resistance at 30 mph, which is attributable to the action of six studs (Fig. 4a) in the tire-ice contact area.

On packed snow (Fig. 4b) the studs also increased the effective coefficient of friction, but to a lesser degree than on ice. The coefficient increased from 0.35 to 0.38 with the addition of studs to the snow tire. This represents about a 9 percent increase in skid resistance at a speed of 30 mph on packed snow.

The studs did not decrease skid resistance on clear pavement, and were slightly beneficial on wet pavements. All dry surfaces exhibited very good skid resistance regardless of the tire used for the test or the amount of surface wear. The reason

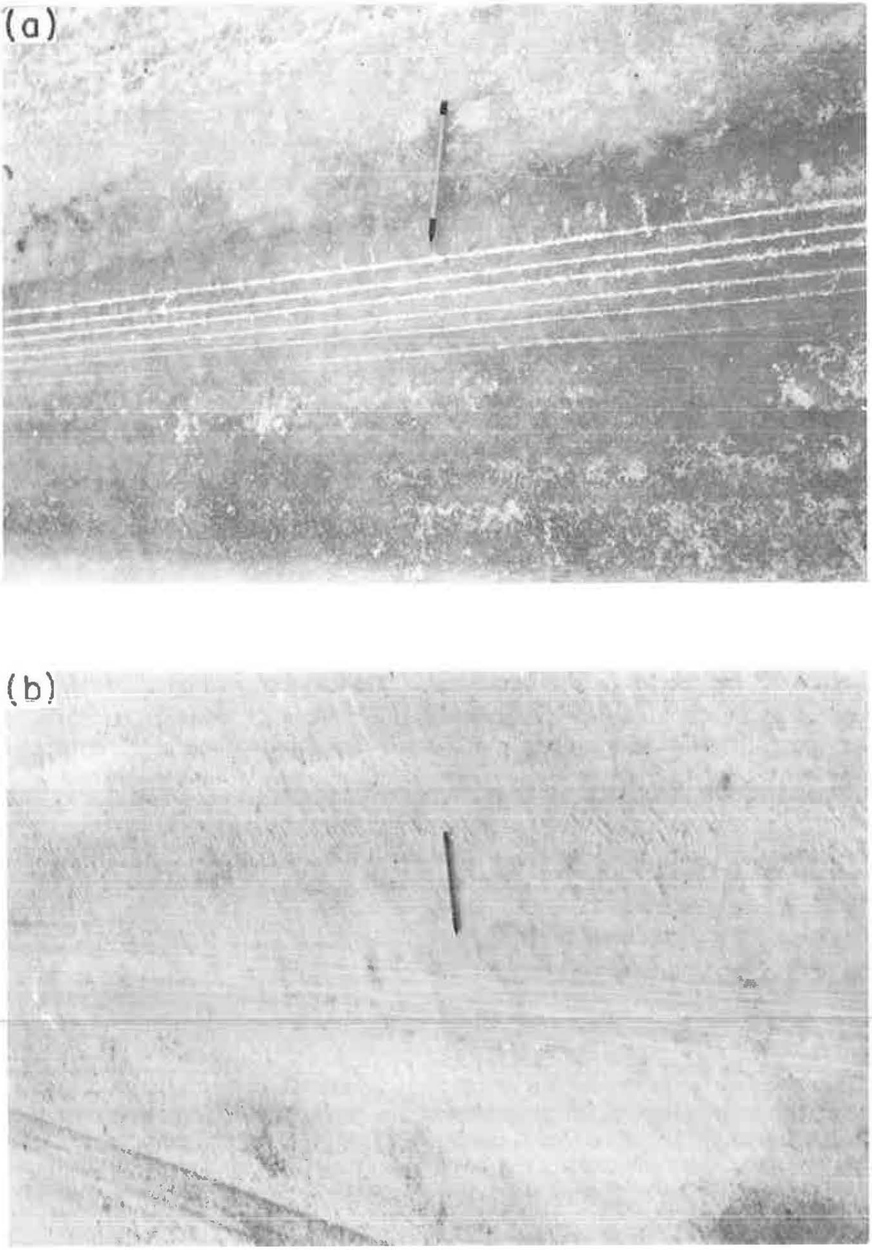

Figure 4. Skid marks on (a) ice and (b) snow.

the studs did not decrease skid resistance on clear pavement was that as the tire stopped rotating, six studs were in contact with the pavement, and this number was not sufficient to lift the tread from the pavement, as evidenced by the amount of black rubber marks in the upper portion of Figures 5a and 5b.

Over 100 individual skid tests with the studded tire were performed on wet and dry New York state highways to determine the extent of surface damage caused by the studs. Since tungsten carbide is very hard, surface scratching was expected when the studded tire stopped rotating and slid across clear pavements. All road surfaces tested were scratched by the

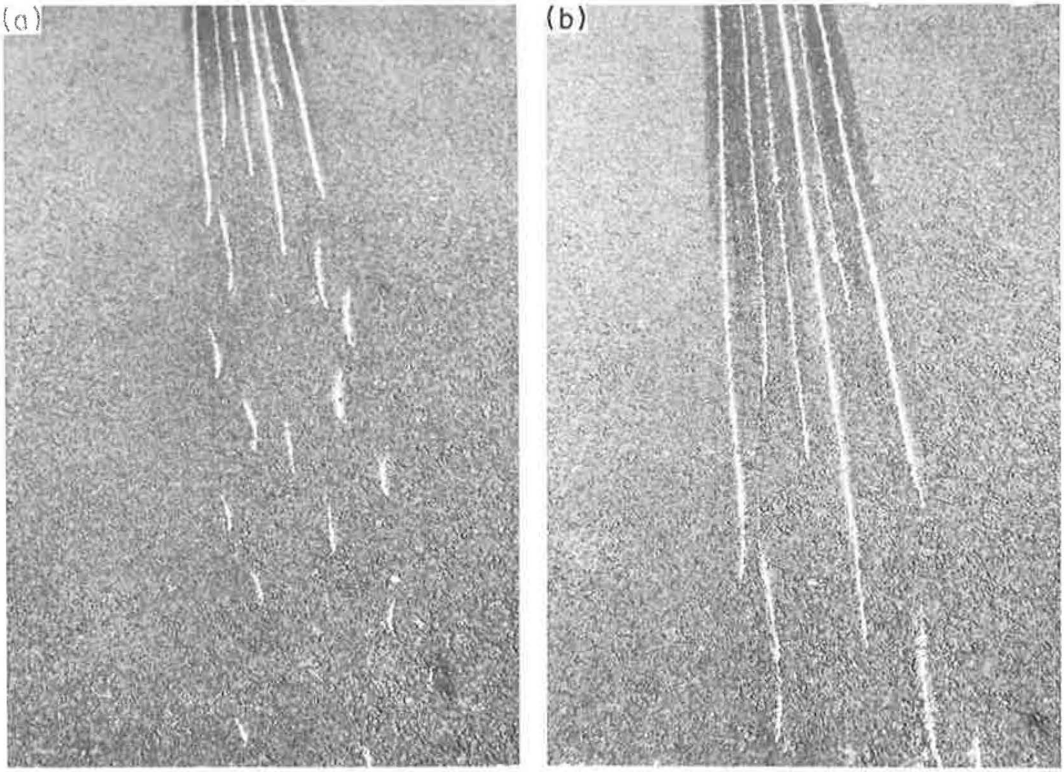

Figure 5. Skid marks on bituminous pavement.

Figure 6. Skid marks on concrete pavement.

sliding studs. When the trailer brakes were first applied and the wheel had not yet stopped rotating, different studs skidded and each one made a short scratch on the surface (Fig. 5). However, when the wheel locked, 6 studs were in contact with the pavement and the scratches became continuous and uniform in depth (less than $^1/_{16}$ in.) on the bituminous pavements (Fig. 5). On concrete surfaces the scratches were very shallow and barely visible (Fig. 6). No aggregate particles were dislodged from the pavement surfaces.

It is felt that scratching of the pavement surface by a sliding studded tire is the most severe damage that can result from a single pass of a vehicle. However, only panic stops are made with the wheels fully locked. Normal braking and accelerating would not slide the studs on the surface since the coefficient of friction on clear pavement is essentially the same with or without studs. Due to the limited time and number of personnel available to perform this special study, pavement wear resulting from the passage of thousands of studded tires was not determined.

CONCLUSIONS

1. The installation of 67 tungsten carbide studs in a 7.75 × 14 snow tire provided about a 40 percent increase in skid resistance on ice at 30 mph.
2. On packed snow the studs increased skid resistance at 30 mph, about 9 percent.
3. At 30 mph, the studs did not decrease the effective coefficient of friction on clear pavements, either wet or dry.
4. The pavement damage caused by the sliding studded tire was not considered significant. However, it was not possible to obtain an indication of pavement wear that might result from extensive use of studded tires on highways carrying large volumes of traffic.

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Test of Steel Studded Snow Tires

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•AS a result of articles in several national magazines, considerable interest has been aroused in a new type of snow tire utilizing a standard snow tread design, but with the addition of a number of tungsten carbide studs set into the tread around its periphery. Oregon law prohibits the use of tires with any metal protuberance, with the exception of the conventional tire chain, and the new tires were therefore declared illegal. Anticipating action during the 1965 legislative session to legalize steel studded snow tires, the Materials Division of the Oregon Highway Department was assigned the task of determining how damaging these steel studs are to pavement so that the Department would know what position to take in this action.

In view of the short time before the legislature was to meet, it was decided to undertake an accelerated comparative wear test initially, and, depending on the results of this test, to conduct subsequently a more prolonged multiple-trip test program.

STATIONARY SPIN TEST

The stationary spin test reported in this paper was intended to simulate what was considered the most severe case of wear, the uphill start from a standstill by an inexperienced driver on thin ice or light loose snow. Under this condition the vehicle might remain nearly stationary with one or both drive wheels spinning for a period of seconds.

The proportion of total driving time represented by the stationary spin test is quite small. During most of the time the steel studded snow tires will be in use, perhaps from October through April, they will be used on streets and highways which are not snow or ice covered, and not at stop signs. The multiple trip test program was intended to simulate the latter type of driving.

Procedure

The test vehicle used in the spin-in-place tests was a $^3/_4$-ton Chevrolet pickup with 4-speed transmission. The hydraulic brake system was modified so that both front brakes and either of the rear brakes could be locked, leaving the other rear wheel free to spin. On the first test the free wheel was raised off the ground using a hydraulic jack equipped with a remote pump and pressure gage. The pickup was then placed in second gear and the wheel was rotated at a constant 500 rpm (20 mph on the speedometer) as it was lowered onto the pavement. A load of 500 lb was applied to the wheel, the balance being taken by the jack. The wheel was spun for a total of 20 sec, of which 5 sec represented the period from initial contact to full application of test load.

For a load of only 500 lb and for a test speed of 500 rpm only the center portion of the tire tread made contact and the pavement was burned and spalled. The second test used a speed of 300 rpm (10 mph on the speedometer) with the full weight of the pickup on the test tire and water lubrication. The full load test time was reduced to 10 sec. All other tests on bare pavement followed this procedure.

For tests conducted on a light snow, the test wheel could be put into rotation without being jacked off the ground. Therefore, the total test duration was reduced to 10 sec. These tests are shown in Figures 1 through 14.

Paper sponsored by the Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

TABLE 1

TEST OF STEEL STUDDED SNOW TIRES, STATIONARY SPIN CONDITION

Test No.	Speed (rpm)	Test Load (lb)	Tire Tested[a]	Location[b]	Cooling	Maximum Scour Pattern (in.)	
						Size	Depth[c]
1	500	500	A	1	None	5.5 × 4.0	0.06, 0.17
2	300	1200	A	1	Water	6.6 × 5.3	0.0 , 0.12
3	300	1200	A	1	Water	7.0 × 5.5	0.0 , 0.12
3a		1200	A	1	Water	25.0 × 5.5 (Brakes slipped)	0.0 , 0.07
4	300	1200	A	2	Snow	7.0 × 6.0	0.10, 0.20
4a	300	1150	B	2	Snow	8.0 × 4.25	0.20
5	300	1200	A	3	Snow	7.2 × 6.0	0.0 , 0.12
6	300	1150	B	3	Snow	7.5 × 4.0	0.0
7	300	1150	C	3	Snow	9.0 × 6.5	0.06
8	300	1150	C	4	Snow	11.0 × 7.0	0.35
9	300	1200	A	4	Snow	9.0 × 6.0	0.25, 0.32
10	300	1150	B	4	Snow	8.0 × 5.0	0.16
11	300	1200	A	5	Water	8.0 × 6.25	0.34, 0.38
12	300	1200	A	5	Water	9.0 × - (In same spot as test No. 11 except moved laterally ½ in.)	0.50, 0.64
13	300	1150	D	5	Water	8.0 × 6.1	0.23
14	300	1200	A	6	Water	8.2 × 5.8	0.05, 0.25
15	300	1200	A	6	Water	8.2 × - (Same spot as No. 14 only moved laterally 1 in.)	0.05, 0.32
16	300	1200	C	6	Water	9.0 × 7.0	0.18
17	300	1200	C	5	Water	18.0 × 10.0	1.5
18	300	1150	D	6	Water	6.5 × 5.0	0.06
19	300	1150	D	7	Water	8.75 × 6.0	0.23
20	300	1150	C	7	Water	13.0 × 7.0	0.48
21	300	1200	A	7	Water	9.0 × 6.35	0.30, 0.40
22	300	1200	E	8	Water	8.5 × 6.0	0.15, 0.28
23	300	1150	D	8	Water	8.0 × 5.0	0.14
24	300	1150	C	8	Water	11.0 × 7.0	0.50
25	300	1200	E	9	Water	9.0 × 6.0	0.25, 0.36
26	300	1150	D	9	Water	8.0 × 5.75	0.14
27	300	1150	C	9	Water	12.0 × 7.0	0.44

[a] A—OK Rubber steel studded extra traction tread on firestone casing.
B—B.F. Goodrich all purpose mud and snow.
C—9-link chain on worn snow tire.
D—OK Rubber extra traction tread without steel studs.
E—OK Rubber steel studded extra traction tread on casing.

[b] 1—Portland cement concrete floor in highway laboratory loading bay.
2—Asphaltic-concrete driveway behind laboratory.
3—Portland cement concrete on old highway 99E southbound connection to Interstate 5 at South Salem interchange.
4—Asphaltic-concrete northbound connection from Interstate 5 to old highway 99E at South Salem interchange.
5—Asphaltic-concrete paved shoulder on northbound on-ramp on Minnesota Freeway ½ mi south of Killingsworth exit.
6—Portland cement concrete northbound on-ramp on Minnesota Freeway ½ mi south of Killingsworth exit.
7—Oil mat pavement on severed portion of Turner Road adjacent to Interstate 5.
8—Asphaltic-concrete pavement on southbound on-ramp to Interstate 5 at Sunnyside-Turner interchange.
9—Asphaltic-concrete pavement on southbound on-ramp to Interstate 5 at North Santiam interchange.

[c] First figure is depth scoured by rubber or chain; second figure is depth scoured by steel stud.

A total of 27 tests was run on new and old asphaltic concrete, and oil mat pavement, new and old portland cement concrete pavement and a portland cement concrete floor. The results of these tests are given in Table 1.

Test Tires

All tires used on this test were of the standard size for this pickup—8.00 × 17.5. Since new steel-studded snow tires were not available except for 14- and 15-in. rims, and OK Rubber "extra traction" tread design recap was placed on a Highway Department 8-ply rating nylon tubeless casing. This is a mud and snow design with four rows of holes spaced across the tread to accommodate up to 144 tungsten carbide studs. The

Figure 1. New OK Rubber Co. "extra traction" tread with 72 tungsten carbide studs.

Figure 2. Tire similar to Figure 1, after 21st test spin; tread 50 percent gone; one stud lost.

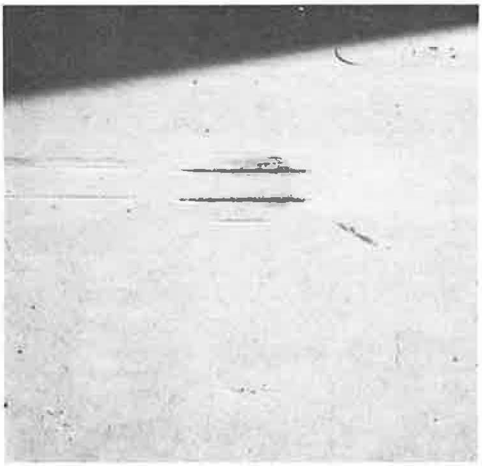

Figure 3. Test no. 3 (portland cement concrete): stud scour 6.8 × 0.12 in. deep.

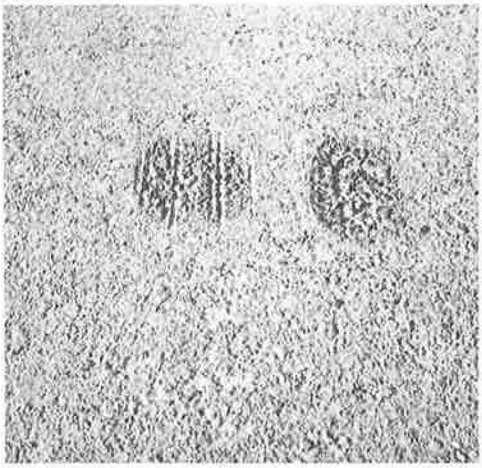

Figure 4. Test nos. 4 and 4a: stud scour, left, 7.0 × 0.20 in. deep; plain snow tire, right, scoured maximum depth of 0.20 in. on oil mat (Goodrich snow tire pattern has narrower width).

tire used in the test utilized only every other hole in each row for a total of 72 studs. The tungsten carbide studs were 0.08 in. in diameter and were encased in flanged steel jackets apparently about 0.25 in. in diameter. Only the tungsten carbide core and the end of the steel jacket are exposed on the face of the tread initially. On the unused tire the ends of the cores extended 0.04 in. above the end of the jacket, and the

Figure 5. Test no. 7 (chain on old portland cement concrete): maximum depth of scour, 0.06 in.

Figure 6. Test no. 12 (two runs of studded tire side-by-side, on new asphaltic-concrete shoulder): scour, 9.0 x 0.64 in. deep; breakout of intervening pavement.

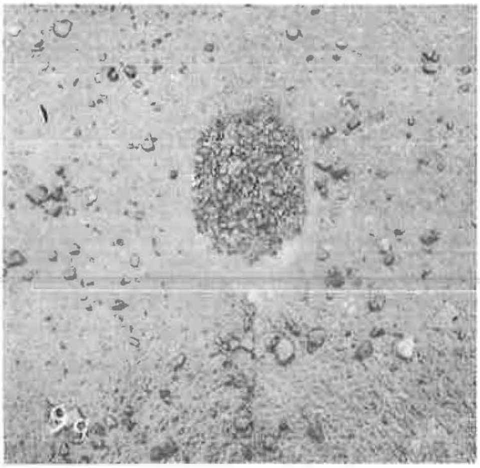

Figure 7. Test no. 13 (OK Rubber Co. "extra traction" tread without studs on new asphaltic-concrete shoulder): maximum depth of scour, 0.23 in.

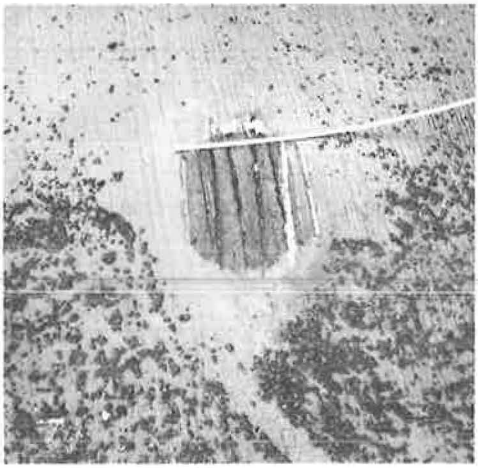

Figure 8. Test no. 15 (two runs of studded tire side-by-side on new portland cement concrete): maximum depth of scour 0.32 in., very little breakout of material between studs.

ends of the cores protruded varying distances out from the face of the rubber tread. A few were flush with the rubber and the majority protruded from 0.05 to 0.10 in. Since the test tire was not subjected to normal wear it is not known whether, under normal conditions, these protruding studs would wear down flush with the rubber, or how

Figure 9. Test no. 17 (chain on new asphaltic-concrete shoulder): maximum depth of scour 1.5 in.

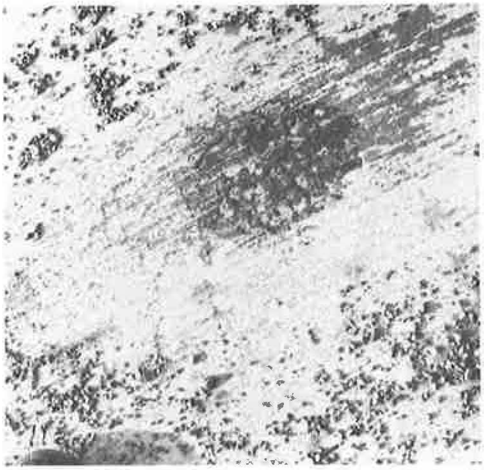

Figure 10. Test no. 18 (plain snow tire on new portland cement concrete): depth of scour, 0.06 in.

Figure 11. Test no. 19 (right edge, plain snow tire on oil mat): scour depth, 0.23 in. Test no. 20 (center, chain): scour depth, 0.48 in.

Figure 12. Test no. 21 (studded tire on oil mat): depth of stud scour, 0.40 in.

long this might take. The depth of the new tread was 0.38 in. to a reinforcing cross lug and 0.50 in. between lugs.

Initial comparative tests were run against a standard B.F. Goodrich "all purpose mud and snow" tire obtained from the Highway Department storeroom. However, this tire had a substantially different contact area from the OK Rubber tire, as well as a

Figure 13. Test nos. 22, 23, 24 (asphaltic-concrete pavement): stud scour depth 0.15 in. (no. 22), plain snow tire scour depth, 0.14 in., maximum; chain scour depth, 0.50 in., maximum (no. 24).

Figure 14. Test nos. 25 (stud), 26 (plain), and 27 (chain). Scour depths: stud, 0.25 in.; plain, 0.14 in.; chain, 0.38 in. (asphaltic-concrete pavement).

slightly different tread design. Subsequent comparisons were made with another OK Rubber "extra traction" tread design recap, but without the steel stud inserts.

The third test wheel consisted of a used 8.00 x 17.5 snow tire equipped with a used tire chain. Eight of the cross links of this chain were of the bar design and the ninth cross link was plain. Experience showed that very little, if any, of the rubber on this tire ever contacted the pavement during the test. The tread showed no sign of wear, whereas the tread of the other two tires was considerably abraded.

Conclusion

The studded snow tires are more destructive to the surface of any type of pavement than plain rubber tires, when rotated in one spot. The total depth of stud scour is dependent on the type of pavement and is a fairly constant depth below the bottom of any scour caused by the rubber. The depth to which the stud will scour is dependent on the amount that the stud projects beyond the surface of the rubber tread, and the location of the stud on the tread. Studs on the edges scoured less than those in the center of the tread. In this test the rubber tread wore down faster than the steel studs, resulting in increasingly greater scour by the studs. Starting with test no. 22 a new tire was used.

On portland cement concrete the steel studded tires scoured to a greater depth than did regular tire chains. On asphaltic pavements the scour by the tire chain was the greater. The total amount of material removed by the tire chain was greater for all pavements. Not only was the total scour pattern larger for the chain, but, unlike the steel studs, the chain removed material from all points within the limits of the scour pattern. A spinning studded tire, if accompanied by sideslip, might remove as large a total volume of material as a chain.

MULTIPLE-TRIP TEST

The results of the spin-in-place test showed that the prolonged use of steel studded snow tires could result in damage to pavement surfaces. It was therefore decided to undertake a multiple-trip test. These tests are shown in Figures 15 through 27.

Test Track Layout

A figure "8" was laid out at the highway shops in Salem on a large parking area paved with an asphaltic-concrete overlay. The asphaltic-concrete was class C, which

Figure 15. Steering pointer attached to pickup.

Figure 16. Initial studded tires after removal at 2,940 trips (27 hr): rear tire, left; front tire, right.

Figure 17. Curve right 4 hr after beginning test (400 trips); studded tires on left.

Figure 18. Left track at middle of curve right at 46 hr (5,330 trips).

differs from class B pavement more commonly used on highways in that the latter uses slightly larger aggregate. The two classes have equal wearing qualities. The "8" consisted of two circles of 76-ft diameter with their centers spaced 126 ft. Tangents to alternate sides of the circles formed a cross-over between the circles. The figure so formed was used as the guidepath.

A pointer 18 ft in length was constructed of $\frac{3}{4}$-in. electrical conduit and fastened to the front of the $\frac{3}{4}$-ton pickup. The outer two feet of this pointer could be seen by the driver and it was his job to drive around the track at a reasonably fast speed, keeping

Figure 19. Right track at middle of curve right at 46 hr (5,330 trips).

Figure 20. Pavement outside test track near middle of curve right.

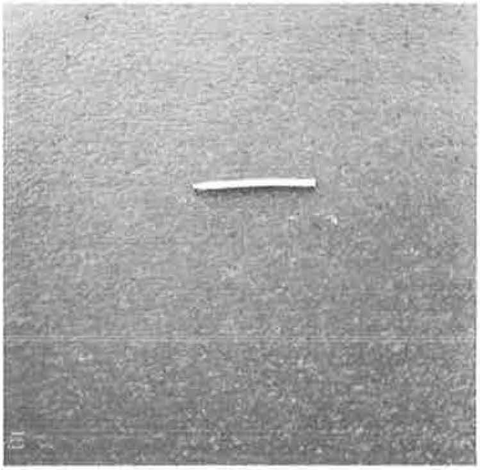

Figure 21. Left track of curve left at 4 hr (400 trips).

Figure 22. Left track of curve left at 29 hr (3,190 trips).

the end of the pointer over the guide track. The wheels of the pickup would then traverse the same path during each trip. This path was 447 ft in length.

About one-fourth the way around one circle the vehicle was braked to a stop and restarted. Maximum speed around the curves was 10 to 15 mph and on the tangents the speed reached 15 to 20 mph. No attempt was made to reach maximum speed on the tangents. Most of the driving was done in the second gear of the 4-speed transmission.

Figure 23. Left track of curve left at 46 hr (5,330 trips).

Figure 24. Right track of curve left at 46 hr (5,330 trips).

Figure 25. Left wheel tracks at cross-over at 46 hr (5,330 trips).

Figure 26. Right wheel tracks at cross-over at 46 hr (5,330 trips).

Test Tires

Approximately 1, 600 lb of gravel was placed in the pickup box to simulate a normal load. With two occupants the weight distribution was as follows:

Left front = 1, 260 lb
Right front = 1, 330 lb

Figure 27. Cross-over area at 46 hr (5,330 trips).

TABLE 2

PAVEMENT WEAR AT VARIOUS POINTS ON TEST TRACK AT END OF THE TEST

Location	Wear
Right wheels, cross-over	0.05 in. or less (avg)
Left wheels, cross-over	0.25 in. (avg)
Right wheels, tangent	0.05 in. (avg)
Left wheels, tangent	0.15 in. (avg)
Right rear, deceleration, curve right	negligible
Right front, deceleration, curve right	negligible
Left rear, deceleration, curve right	0.25 in. (approx.)
Left front, deceleration, curve right	0.35 in. (approx.)
Left rear, acceleration, curve right	0.20 in. (avg)
Left front, acceleration, curve right	0.15 in. (avg)
Right rear, acceleration, curve right	0.05 in. (approx.)
Right front, acceleration, curve right	0.05 in. (approx.)
Left rear, curve left	0.10 in. (avg)
Left front, curve left	0.12 in. (avg)
Right rear, curve left	0.15 in. (avg)
Right front, curve left	not measurable

Left rear = 1,730 lb
Right rear = 1,750 lb
Total = 6,070 lb

The alternate driver did not ride during the test, however, due to a tendency to become car sick; each driver could stand the motion for only half an hour at a time.

The initial tire arrangement was as follows:

Left front: original steel studded snow tire, which was removed from the stationary spin test after test no. 21, with 50 percent of the tread remaining.

Left rear: comparatively new steel studded snow tire, subjected to two spin tests before this phase.

Right front: used snow tire which had been used with the chain in the stationary spin tests.

Right rear: nonstudded OK Rubber Co. recaps used in the stationary tests.

After 2,100 trips the studded snow tires started losing studs from the center two rows. When the tires were removed at the end of 2,940 trips only 4 studs remained in the inner rows of the front left tire and 3 studs remained in the inner rows of the left rear tire. The outer rows lost no studs.

The two new replacement tires were also OK Rubber Co. extra traction recaps with 72 studs each. However, these studs were in plastic jackets rather than metal jackets as used in the first two tires. According to the supplier, the two types of studs are of equal quality. After completing 2,390 trips with the new tires 2 studs were found missing, both from the rear tire.

Wear Measurements

To determine the amount of pavement wear resulting from the numerous passes over the same track, cross-sections were directly drawn at 16 different locations before and after testing. The wear showed up as the difference between these two lines.

Gage points, spaced 18 in. or more so as to bracket the tire track, were laid out as the pickup was slowly moved around the figure "8" with the pointer directly over the line. PK masonry nails were used for this purpose.

After 400 trips, the vehicle made a wider curve at test speeds than anticipated and the cross-sections had to be extended an additional 18 in. Also, it became apparent, late in the test, that several of the center gage points on these extended sections were being driven into the pavement as the particles of pavement were eroded from around them. This made it more difficult to determine accurately the loss of material from the tire track on curves.

The initial gage point layout had anticipated that on the curves each wheel would make a separate track. It soon became obvious that, due to difficulty in keeping the pointer exactly on the guideline and because of sideslip in the vehicle, only two tracks would be distinguishable: right wheels and left wheels. Although measurements are identified as left rear and left front, each actually represents wear resulting from both left wheels, and could be averaged.

The wear measurements at the end of the test are given in Table 2.

Conclusions

Early in the test the wear caused by the steel studs consisted of the removal of the fine sand-size material from the surface of the pavement. Evidence of the action of the studs could be seen as lateral scratch marks on the curves. This roughening of the surface took place fairly rapidly, much of it occurring during the first 2,100 trips. Continuing rains prevented taking satisfactory progress photographs or measurements.

The last 3,200 trips continued to remove material, but at a slower rate. The action appeared to be, generally, a continued picking out of fine material from around the larger pieces of aggregate, with some smoothing of the large aggregate. Softer aggregates would undoubtedly wear away at a faster rate.

Some areas of more open texture, evidenced by a coarse appearance of the asphaltic-concrete surface before the test, were abraded at a faster rate than surrounding materials. These areas might have developed into chuck holes had the test been continued.

The approximately 5,330 trips made by the test vehicle on the tangents represent 10,660 passes by standard vehicles, with studded tires only on the rear, since both the studded tires were on the same side of the test vehicle. In the cross-over area the wear represents the passage of 21,320 vehicles with studs on the rear. On the curves the wear was spread out over tracks 18 to 24 in. wide. At the cross-over and on tangents the wear was concentrated in an area approximately 12 in. wide.

To equate the wear experienced during this test to that which might be experienced on an actual highway, consider the Baldock Freeway north of Salem. The average daily traffic volume in both directions is 14,000 vehicles. If the traffic is equal in both directions and 60 percent of these 7,000 vehicles use the outer lanes, the daily volume in these lanes would be 4,200 vehicles. These vehicles will wander within the boundaries of the lanes, but most of them will travel with left or right wheel in a track 3 ft wide. The density within each foot of width of this track is therefore approximately 1,400 veh/day. If 25 percent of these vehicles are equipped with steel studded snow tires on the rear wheels, it will take approximately 30 days to make 10,660 passes and to wear 0.15 in. off the surface, or 60 days to wear 0.25 in. off the surface, if the wear at 70 mph is no greater than that at 20 mph. Closer to Portland, where the average daily traffic volume is 30,000 veh/day, the time required to erode 0.15 in. is reduced to 14 days and 0.25 in. of erosion could occur in 28 days. In this analysis, the further assumption is made that the class B asphaltic concrete on the freeway will erode the same as the overlay tested.

Some Tests of Studded Tires in Illinois

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•EXTENSIVE testing in Europe and in this country has shown that pneumatic tires equipped with tungsten carbide studs embedded in the treads produce traction on icy and hard-packed snow surfaces that is much superior to the traction produced by standard tires.

Studded tires have been widely accepted in Europe where they were introduced a few years ago, and similar acceptance can probably be anticipated in this country now that principal tire manufacturers are introducing the tires here.

It is generally acknowledged that studded tires have an abrasive effect on pavement surfaces; however, there is considerable difference of opinion and little factual information on the severity of the abrasive action likely to take place.

Laws enacted many years ago in a number of states, including Illinois, apparently make the use of studded tires illegal. These laws, although not intentionally directed against the use of studded tires at the time of enactment, were put into effect to protect pavement surfaces against excessive wear.

Because of the proven safety features of studded tires on ice and packed snow, consideration must be given to permitting their use. However, the benefits to be derived from the use of studded tires must be weighed against the expense that may be incurred if they cause excessive damage to pavement surfaces. Other possible disadvantages must also be examined in their appraisal.

Unlike tire chains, studded tires are likely to be used continuously during the entire winter season, on dry pavement as well as on ice and packed snow. Therefore, damage to dry pavement surfaces through repetitive passages of tires equipped with metal studs becomes an important factor.

To obtain some general information on the likely effects of studded tires on dry pavement surfaces, a short pilot study using vehicles equipped with these tires was conducted during the winter and spring of 1965 on the grounds of the Physical Research Laboratory of the Bureau of Research and Development, located 5 mi northwest of Ottawa, Ill. At the site, three different types of pavement surfaces were available for testing with no inconvenience to the traveling public. The major objective of this study was to develop information on the abrasive effects of studded tires on typical Illinois pavement surfaces.

A supplementary study of the traction of studded tires on dry concrete was also made when it appeared during the abrasion tests that the studded tires were not performing as well as standard tires on dry surfaces.

Automobile tires equipped with tungsten carbide studs embedded in the treads were tested under constant speed (25 mph) and under a series of starts and stops on portland cement concrete, bituminous concrete, and a bituminous surface treatment (Illinois subclass A-3). A test was also made with regular tires on the portland cement concrete. All of the pavements were constructed in 1958. The bituminous-treated surface has carried local traffic since that time, but neither the portland cement concrete nor the bituminous concrete surfaces had carried traffic previously. In some of the tests, a steel beam equipped with Ames dials was used to measure changes in the pavement surface. Photographs and plaster-of-paris casts were made for visual evidence of damage to the pavement surfaces caused by the studded winter tires.

Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

Figure 1. Loop 1 of AASHO Road Test, where studded tire test was conducted.

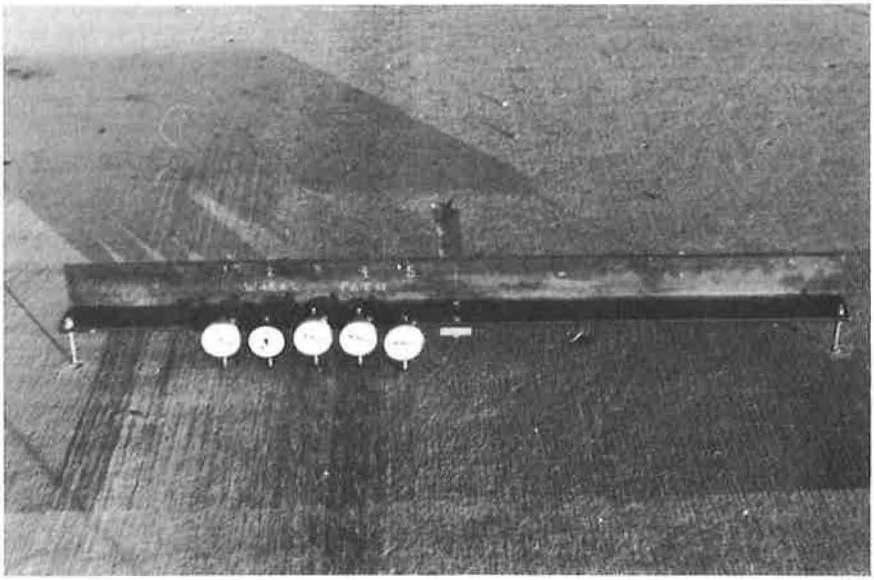

Figure 2. Beam used to measure pavement surface depression in wheelpath at each test site.

In view of the pilot nature of the study, and a desire to obtain general information quickly, most of the results obtained were necessarily qualitative, with quantitative measurements being at a minimum. The device developed for measuring the depths to which surface abrasion extended under application of the studded tires was not perfected until late in the test program.

Within the foregoing limitations, the study showed that wide use of tires having tungsten carbide studs embedded in the treads can be expected to cause abrasion in the

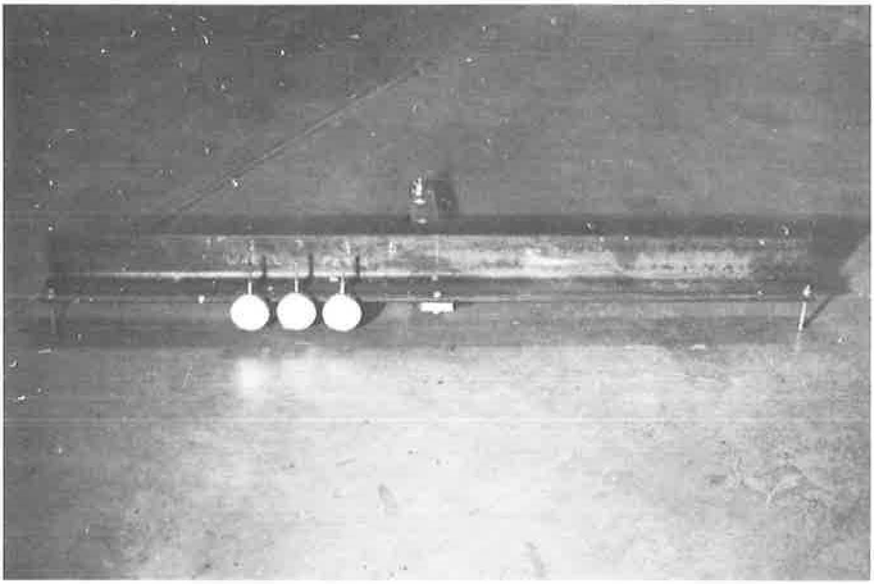

Figure 3. Beam with new dials used in special tests

wheelpaths of highway pavement surfaces. This abrasion undoubtedly would be most severe at intersections and at other locations where vehicles might be expected to make frequent starts and stops or sharp turns.

These statements are based on visual evidence of surface abrasion caused by studded tires on three principal types of pavement surfaces, and on measurements of depth of abrasion made on a dry portland cement concrete pavement. Measurements made on the portland cement concrete pavement with the steel beam equipped with Ames dials indicated that the pavement surface was abraded to a depth of almost $^1/_{16}$ in. in 50 start and stop applications (25 rapid starts followed by 25 emergency stops).

Evidence also indicated that, on dry pavements, vehicles equipped with studded tires require greater distances for stopping than vehicles equipped with regular (standard non-snow tread) tires.

EXPERIMENTAL PROCEDURE

Initially, seven test sections were marked with paint on the pavement surfaces of the east half of loop 1, the one remaining loop of the AASHO Road Test facility (Fig. 1). Of these, three were on a portland cement concrete surface andfour were on a bituminous-concrete surface. One section on each type of pavement was designated for start tests, one for stop tests, and one for constant speed (25-mph) driving. The fourth section on the bituminous-concrete surface was located on the turnaround at the east end of the loop, and was used for observing the effect of the studded tires while turning. Starts and stops were both the normal (with no spinning or sliding of the wheels) and the emergency type (with wheels spinning to start and sliding to stop). Normal start and stop tests preceded the emergency start tests and stop tests on a given test section.

Each test section was subjected to 250 passes of a vehicle equipped with studded tires. An eighth test section on the bituminous surface-treated pavement of the adjacent township road was subjected to a limited number of start and stop tests. Twenty-five emergency starts followed by 25 emergency stops were applied to this section.

A steel beam on which Ames dials were mounted (Fig. 2) was set on gage plugs cemented into the pavement with the dials in the wheelpath at each test site. The beam and dials were used to measure changes in the pavement surface. Measurements were made before the tests were started and after successive sets of applications at each test section. Unfortunately, the device did not function satisfactorily until near the end of the test series.

Photographs were taken of the test sections before the test and after each set of applications. Plaster-of-paris casts were made in the wheelpaths of the sections designated for start and stop tests at the beginning, after 200 applications, and after completion of all test runs.

At the conclusion of the main test series, three special tests on portland cement concrete surface were added, using a new arrangement of Ames dials and a modified measurement procedure that showed promise of giving more reliable measurements of abrasion depth (Fig. 3). Photographs and plaster-of-paris casts were also made of some of the special sections. A special test consisted of 25 rapid starts followed by 25 emergency stops across the test section. Measurements were made before and after each set of applications. At least ten minutes was allowed for the beam to become stabilized at equilibrium with the air temperature before taking initial readings. Measurements made in this way were reproducible.

The special tests were conducted on both a dry and an icy portland cement concrete surface with studded tires, and on a dry portland cement concrete surface with standard tires.

Two Allstate and four Goodyear studded snow tires, together with several standard tires, were used in the tests. The two Allstate tires had 52 tungsten carbide studs per tire equally spaced around the circumference in four rows, two rows along each edge of the tread. Studs were set approximately flush with the tread surface, ranging from slightly below the surface to about $^1/_{32}$ in. above it. These two tires were mounted on the rear wheels of a 1961 Plymouth sedan. The Goodyear studded tires contained from 103 to 108 tungsten carbide studs per tire, also arranged in two rows along each edge of the tread. The studs on these tires protruded on the average about $^3/_{32}$ in. above the surface of the tread. The Goodyear tires were mounted on all four wheels of a 1962 Chevrolet station wagon (Fig. 4).

The Chevrolet was used in the first series of tests that included regular driving and starts and stops. For the subsequent special rapid-start and emergency-stop tests, the Plymouth was used for the starts, and the Chevrolet for the stops. Only the Chevrolet was used in the stopping distance tests.

Figure 4. Chevrolet station wagon with studded tires on all four wheels.

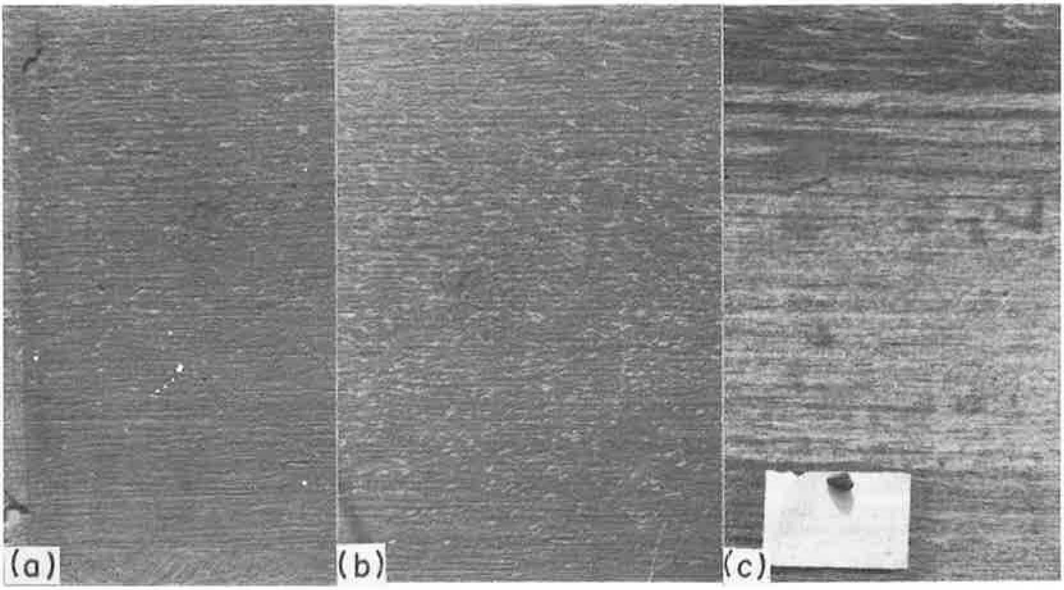

Figure 5. Portland cement concrete pavement surface after (a) 25 normal starts, (b) 125 normal starts, and (c) 175 normal starts plus 75 rapid starts.

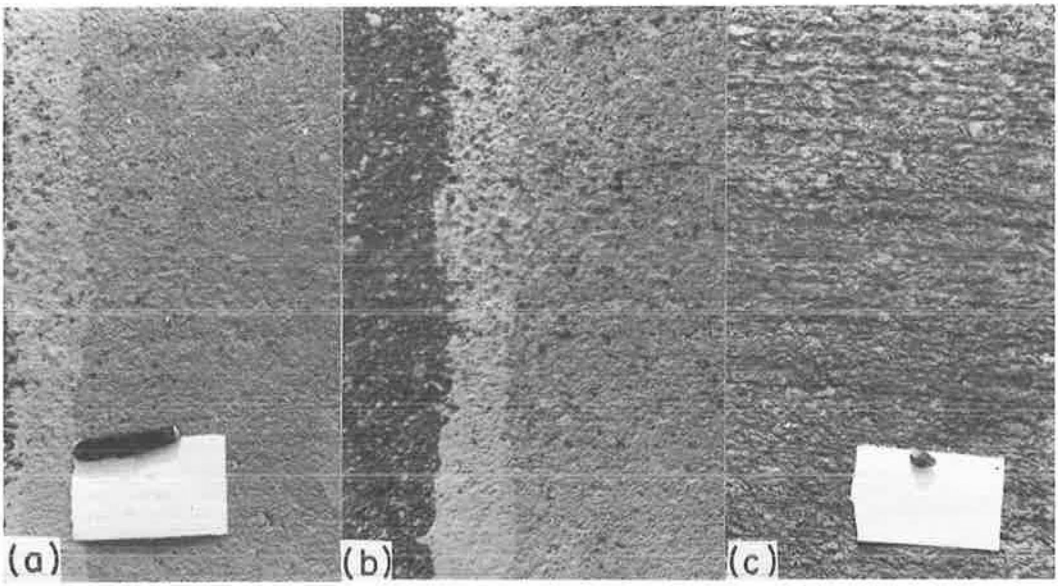

Figure 6. Bituminous-concrete pavement surface after (a) 25 normal starts, (b) 125 normal starts, and (c) 175 normal starts plus 75 rapid starts.

TEST RESULTS

Starting Tests

The starting tests included a series of normal and rapid starts over a test section of portland cement concrete pavement and a test section of bituminous-concrete pavement.

A complete series of tests over a section included 175 normal starts (starting without spinning rear wheels) followed by 100 rapid starts (starting under full power with spinning rear wheels).

Figure 5 shows the portland cement concrete pavement surface after 25 normal starts, after 125 normal starts, and after 175 normal starts followed by 75 rapid starts. The bright scratches crossing the burlap drag marks in the view taken after 25 applications are striations in the pavement surface made by the tire studs. After 125 applications of normal starts the stud marks were more numerous and the burlap drag marks were beginning to disappear. The abrasion of the pavement surface was much greater under rapid-start testing. Abrasion by the studded tires after 250 applications (175 normal starts plus 75 rapid starts) extended completely through the original surface in the center of the wheelpath, and a new surface was exposed (Fig. 5).

The condition of the bituminous-concrete surface at various stages during the starting tests is shown in Figure 6. The dark line to the left in Figures 6a and 6b indicates the limits of the painted area in the test sections. The effects of studded tires in starting on the bituminous-concrete surface were about the same as those on the portland cement concrete surface. The dark specks in Figures 6a and 6b are gouges in the pavement surface made by the metal studs. Figure 6c shows the surface after 250 applications (175 normal starts followed by 75 rapid starts). The paint was completely removed and the pavement surface markedly abraded.

Stopping Tests

A series of 175 normal stops followed by 75 emergency stops was run on both the portland cement concrete surface and the bituminous-concrete surface. A normal stop consists of stopping the test vehicle without sliding the tires; emergency stops were made with the wheels locked.

The progression of damage to the surface of the portland cement concrete pavement with succeeding applications of stops is shown in Figure 7. The light-colored marks in Figures 7a and 7b were made by the studs when brakes were applied without locking the wheels. Inadvertently, brakes tended to lock and some sliding of the tires occurred during the normal stops. Figure 7c was taken after application of 175 normal stops

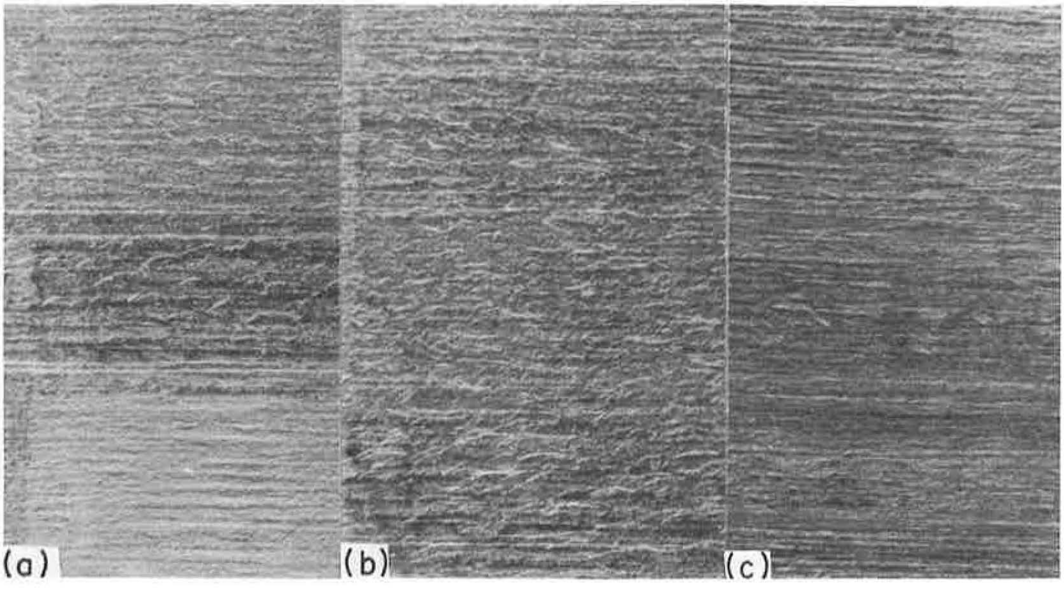

Figure 7. Portland cement concrete pavement surface after (a) 25 normal stops, (b) 125 normal stops, and (c) 175 normal stops plus 75 emergency stops.

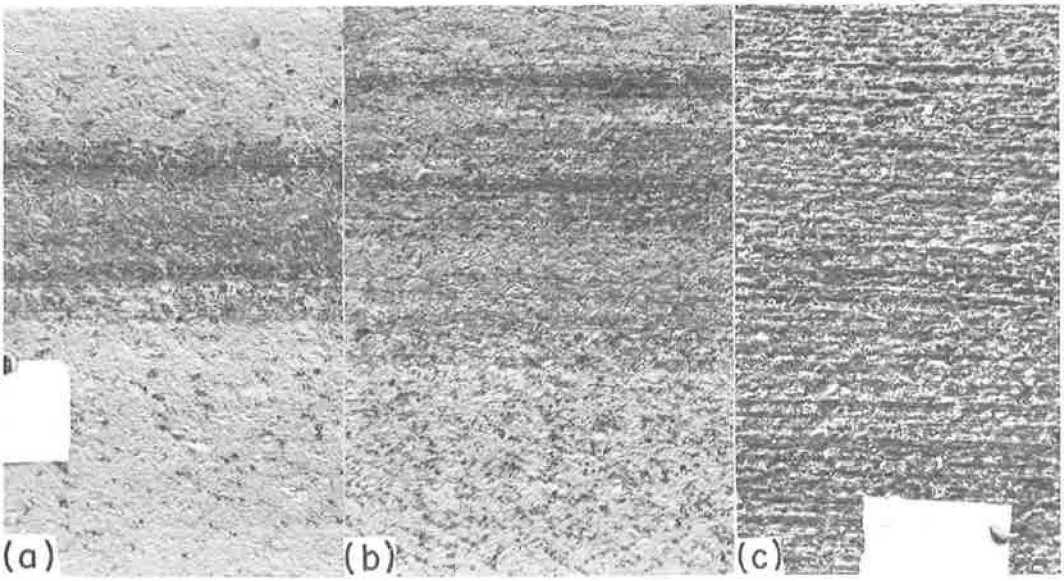

Figure 8. Bituminous-concrete pavement surface after (a) 25 normal stops, (b) 125 normal stops, and (c) 175 normal stops plus 75 emergency stops.

Figure 9. Bituminous-concrete surface after application of 175 normal stops followed by 25 emergency stops.

followed by 75 emergency stops. By this time, abrasion of the pavement surface had reached the point that the burlap drag marks had been completely obliterated in the center of the wheelpath.

Similar results were obtained during the stopping tests on the bituminous-concrete surface (Fig. 8). As with the stopping tests on the portland cement concrete surface, emergency stops with the wheels locked caused the greatest amount of abrasion of the pavement surface (Figs. 8a and 8b).

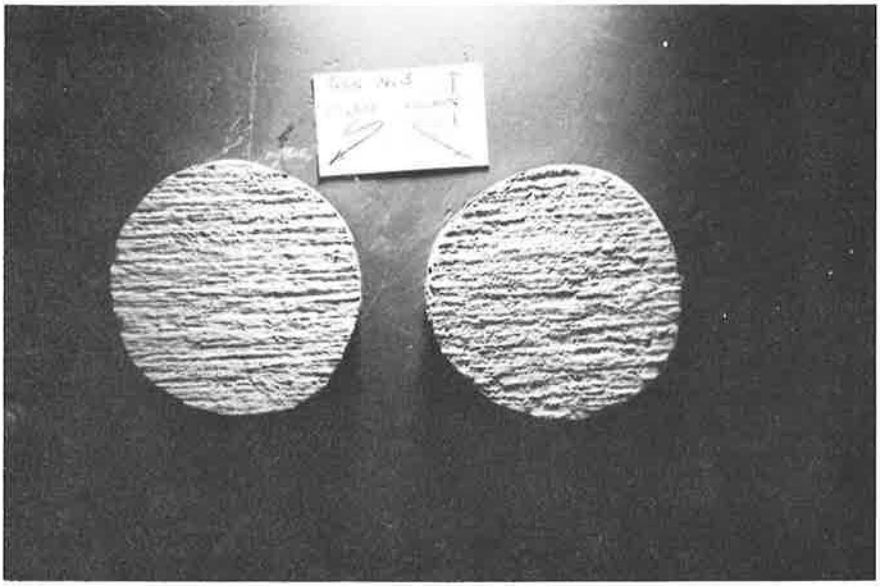

Figure 10. Plaster-of-paris casts of surface of portland cement concrete pavement before testing (left) and after 200 stop applications (right).

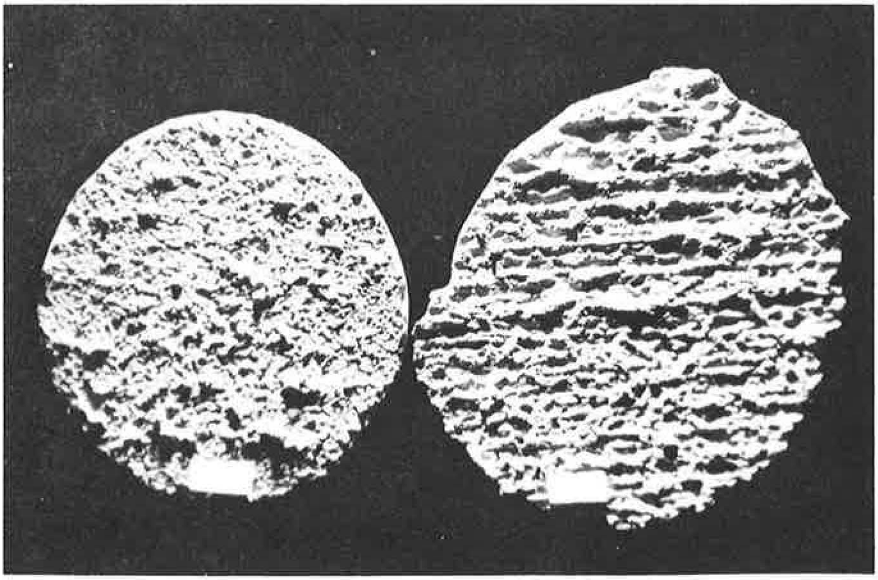

Figure 11. Plaster-of-paris casts of the surface of bituminous-concrete pavement before testing (left) and after 200 stop applications (right).

On the stopping test section of the bituminous-concrete pavement the paint mark was completely obliterated in the wheelpaths and abrasion of the surface was evident after 175 normal stops followed by 25 emergency stops (Fig. 9).

Comparisons of plaster-of-paris casts of the pavement surface made before testing and after the application of 175 normal stops followed by 25 emergency stops are shown in Figures 10 and 11.

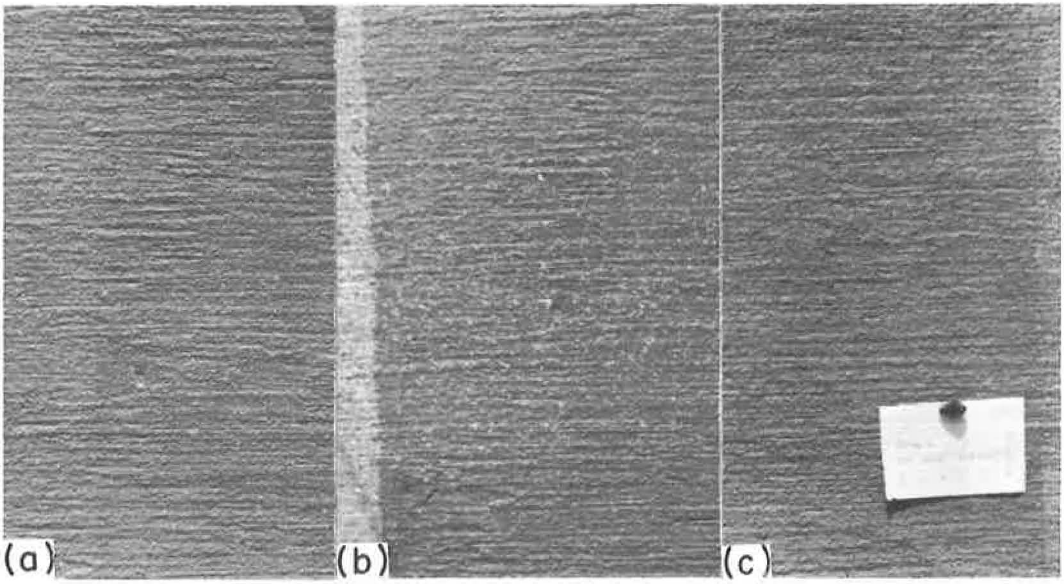

Figure 12. Portland cement concrete surface after constant-speed testing: (a) 25 applications, (b) 125 applications, and (c) 250 applications.

Constant-Speed Tests

One test section of portland cement concrete pavement and one of bituminous-concrete pavement were used for testing studded tires with the vehicle operating at a constant 25-mph speed; 250 applications of the vehicle were made on each section (Figs. 12 and 13). Abrasion in this series of tests was indicated only as small pock marks, which appear as white dots (Fig. 12) and as black specks (Fig. 13). Abrasion of the pavement surfaces during constant-speed testing was very minor, although the marks in the wheelpaths were clearly visible at the end of testing.

Turning Tests on Bituminous-Concrete Surface

The abrasive effects of turning on a bituminous concrete surface appeared to be intermediate between those occurring under constant-speed driving and those occurring under starting and stopping. Turning produced stud marks or striations in the pavement surface that were almost normal to the direction of travel because of the twisting effect as the vehicle turned. Figure 14 shows the bituminous-concrete surface after 25, 125, and 250 applications. The test pavement has a 20-ft radius along the inside edge, which is similar to the turning radius at many intersections.

Material loosened by the abrasive action of the studs was clearly visible on the pavement surface.

Starting and Stopping Tests on Subclass A-3 Surface Treatment

A series of 25 rapid starts followed by 25 emergency stops was applied to the subclass A-3 bituminous-treated surface of the township road that parallels loop 1. The studded tires caused deep abrasion of the A-3 treatment (Figs. 15 and 16). Figure 15 shows the pavement surface after completion of the testing; Figure 16 shows the plaster-of-paris casts made before and after testing, with the severity of grooving indicated by the left-hand cast.

Special Tests

An effort was made to develop instrumentation for obtaining quantitative measurements of the depths of surfacing removed by the studded tires. After the tests were

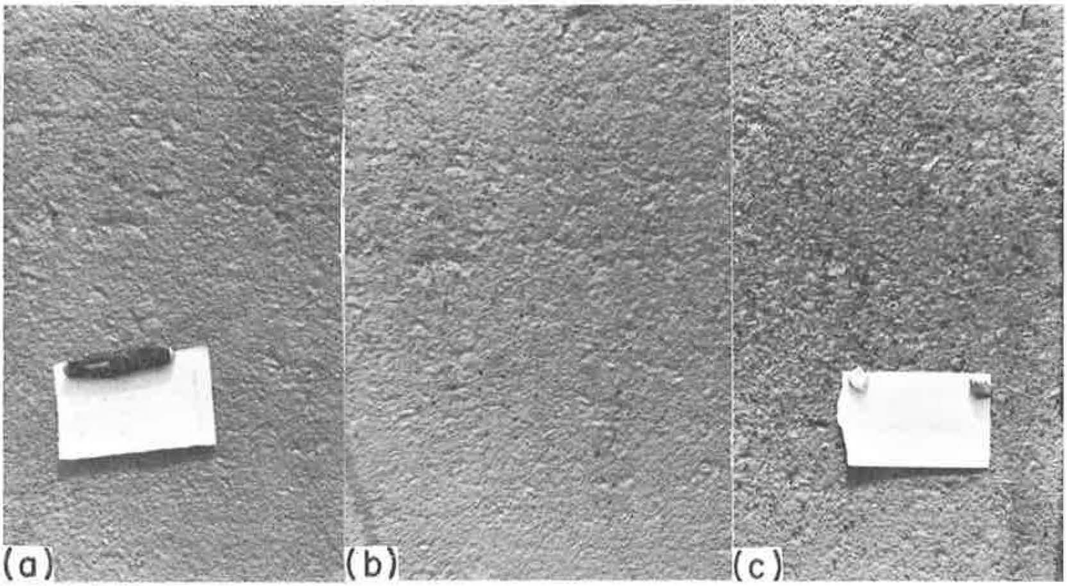

Figure 13. Bituminous concrete surface after constant-speed testing: (a) 25 applications, (b) 125 applications, and (c) 250 applications.

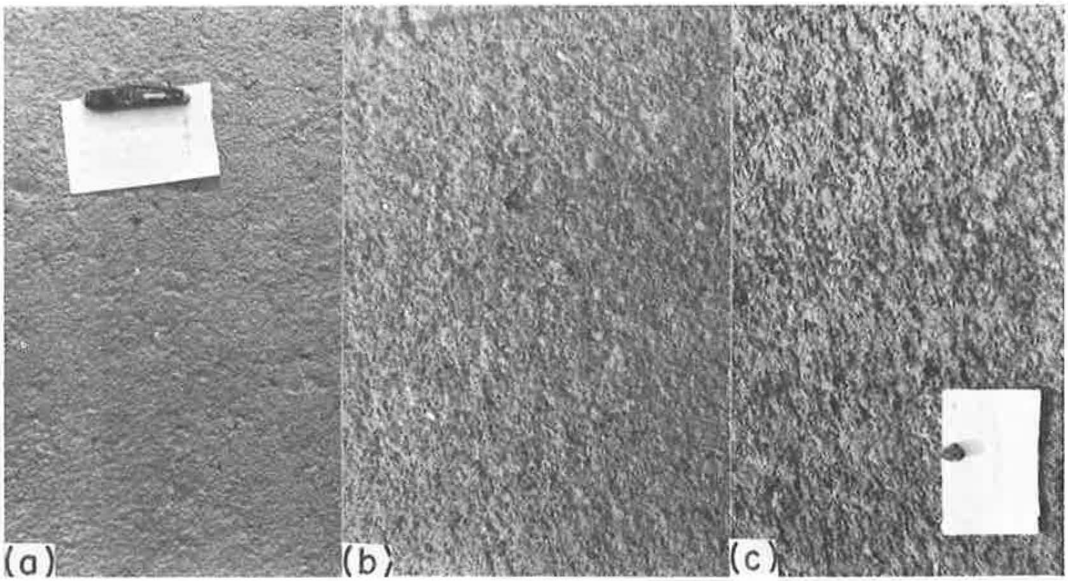

Figure 14. Turning tests on bituminous concrete surfaces after (a) 25 applications, (c) 125 applications, and (c) 250 applications.

begun, it was found that the instrumentation was not yielding reliable results. Because of the pilot nature of the tests, the need to complete them quickly, and the uncertainty concerning the length of time required to develop satisfactory instrumentation, the originally planned series of tests was completed without the instrumentation.

Following completion of the original series of tests, the instrument developed for measuring depth of surface abrasion under studded tires was modified in an attempt to improve its reliability. When it appeared that some success had been attained, a

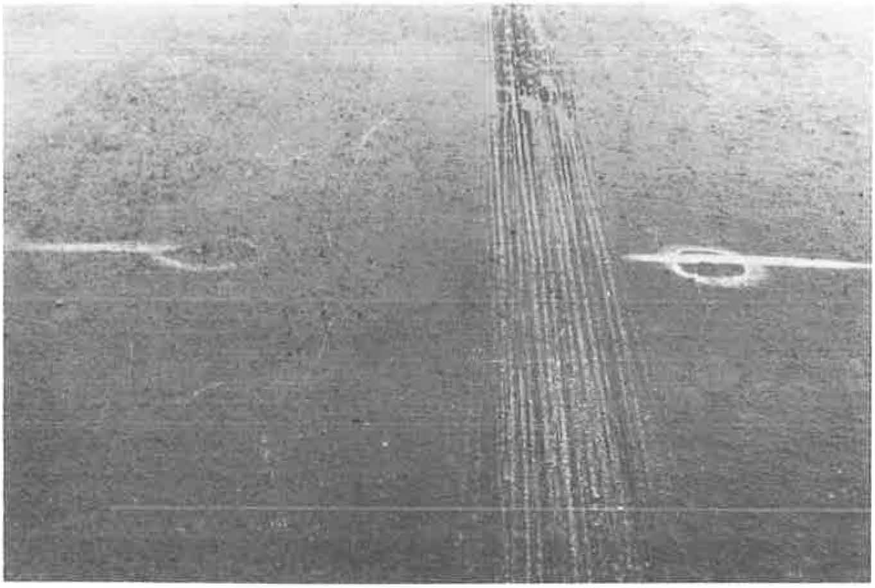

Figure 15. Subclass A-3 surface treatment after completion of testing.

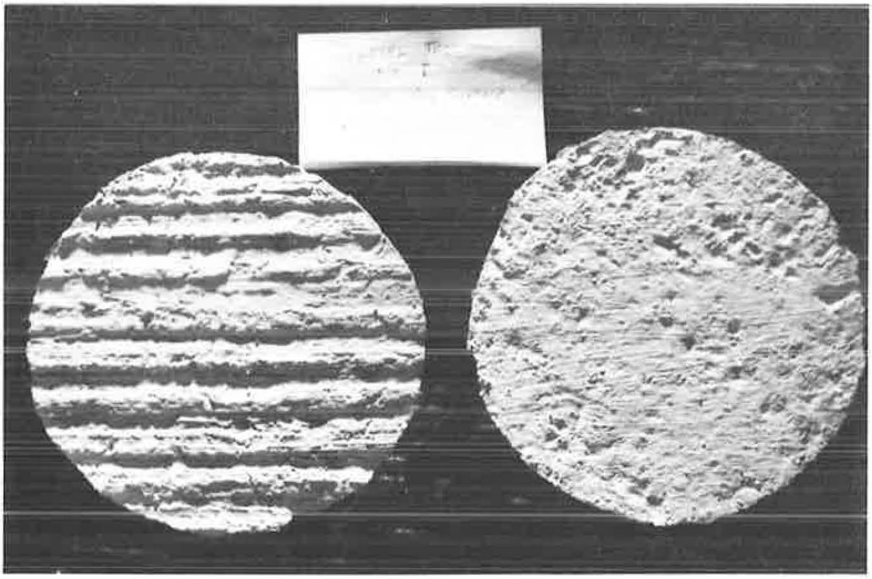

Figure 16. Plaster-of-paris casts of A-3 surface treatment before testing (right) and after completion of testing (left).

second series of field tests of studded tires was undertaken. Because the additional information to be gained through the use of the modified instrumentation did not appear sufficiently important to warrant a complete repetition of the original tests, the test schedule was modified.

The modified instrument consisted of fewer Ames dials mounted on a short portion of the original beam.

TABLE 1

AVERAGE DEPRESSION OF WHEELPATH DURING 50 APPLICATIONS OF RAPID STARTS AND EMERGENCY STOPS[a]

Treatment	Avg. Wheelpath Depression (in.)		
	Dry PCC[b]	Icy PCC[b]	Dry PCC[c]
25 rapid starts	0.040	0.017	0.004
25 rapid starts and 25 emergency stops	0.043	0.019	0.004

[a] Dial readings taken in triplicate and averaged for wheelpath depression for each test.

[b] Tested with studded tires.

[c] Tested with regular tires.

The special tests included 25 rapid starts followed by 25 emergency stops on each of three test sections: (a) a section of dry portland cement concrete tested with studded tires; (b) a section of ice-covered portland cement concrete tested with studded tires; and (c) a section of dry portland cement concrete tested with regular tires. Results are given in Table 1.

Dial readings indicated that surface abrasion took place in all three special tests. The amount of abrasion from regular tires was appreciably less than that produced by the studded tires. The effect of studded tires on the icy surface was less than on the dry surface.

Dry Portland Cement Concrete Surface, Studded Tires.—Abrasion of the pavement in this special test (Figs. 17 and 18) appeared similar to that resulting from the original starting and stopping tests.

Icy Portland Cement Concrete Surface, Studded Tires.—Water was poured over the surface of the pavement and allowed to freeze solid (Figs. 19 and 20). For the initial beam measurements the ice was chipped away under each dial. After three applications of rapid starts, two sets of grooves had been cut through the ice into the pavement surface by the studs (Fig. 19). The same type of grooving was evident at all test sections where serious damage occurred as a result of spinning the wheels during rapid starts. During this test, the initial grooves appeared quickly and the studs tended to slip into the grooves on successive passes, widening the grooves and rounding off the ridges between the grooves. Grooving did not appear to be increased in intensity as a result of the ice on the surface. After 25 applications of rapid starts, all of the ice had been removed from the wheelpaths and pronounced grooves had been made in the pavement surface (Fig. 20). Chips on the surface are ice fragments chipped out of the wheelpath.

Dry Portland Cement Concrete Surface, Regular Tires.—This study was conducted as a control test using regular tires. On completion of testing, there was no evidence of the test except for the black rubber marks caused by spinning and sliding the tires (Fig. 21).

Traction Tests

This test series was to obtain information on the relative stopping distances required by vehicles mounted on studded snow tires and on standard tires. A general impression that the studded tires required greater stopping distances during the abrasion tests indicated the desirability of this supplementary study.

The Chevrolet station wagon was used in all the stopping-distance tests, and the same driver was used throughout the series. The same studded Goodyear tires were also used.

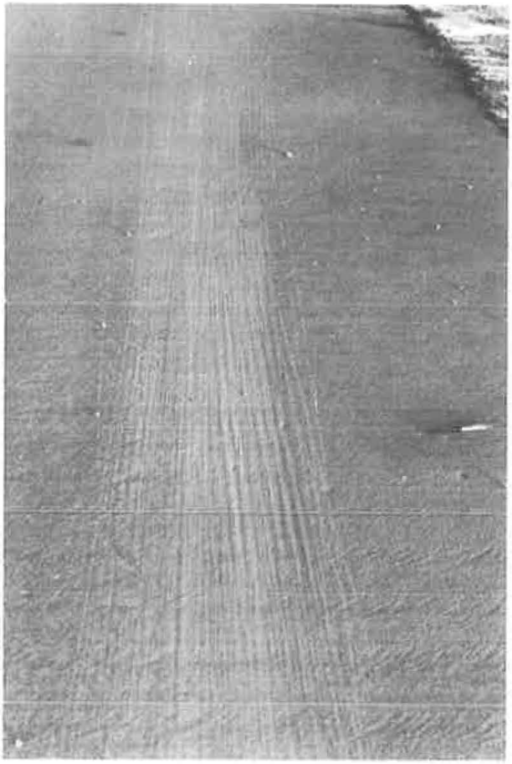

Figure 17. Special test no. 1 on portland cement concrete; pavement surface after completion of tests.

Figure 18. Special test no. 1; pavement surface after completion of tests.

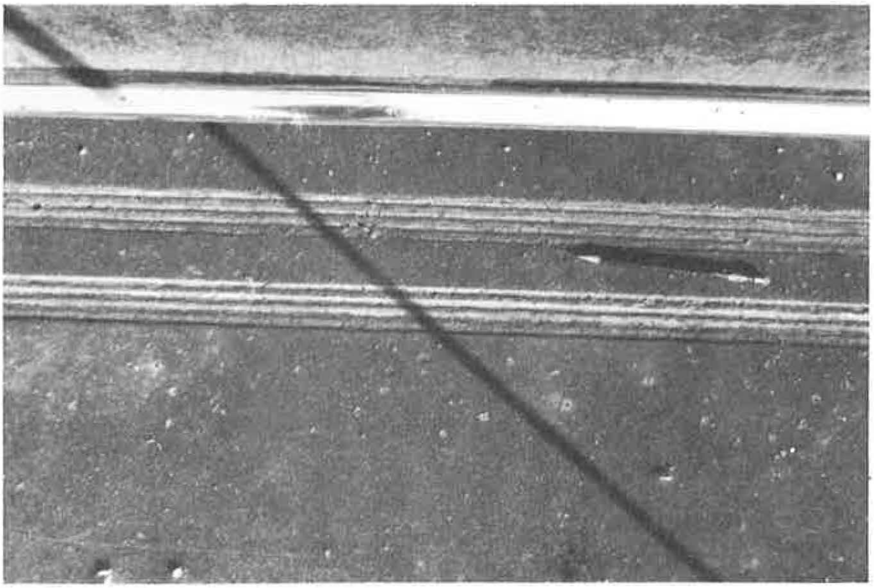

Figure 19. Special test no. 2; icy portland cement concrete surface after three applications of rapid starts.

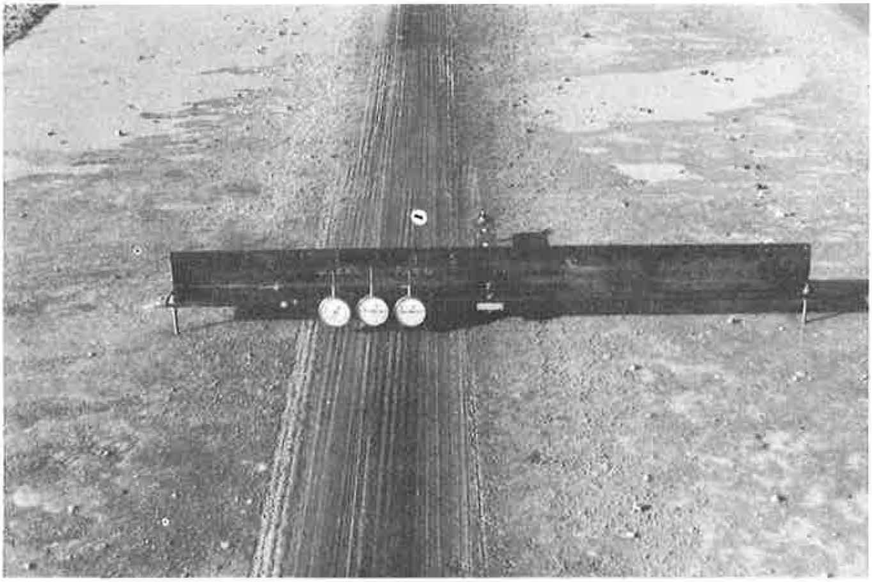

Figure 20. Special test no. 2, surface after completion of tests.

A toy pistol firing a dart with a rubber suction cup triggered by a solenoid activated by the brake was used to mark the pavement at the start of braking action. The dart cup was dabbed with wet paint to mark the pavement surface. Stopping distances were measured from the paint mark to the gun muzzle on the rear bumper of the stopped vehicle.

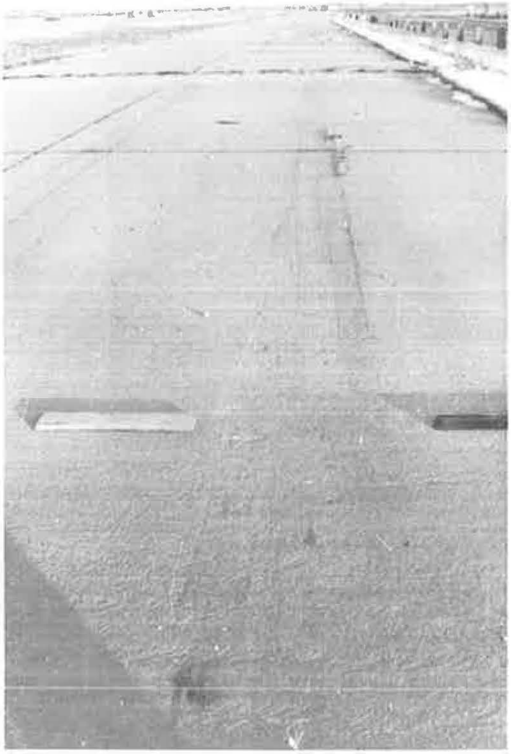

Figure 21. Special test no. 3 on dry portland cement concrete pavement with regular tires, after completion of test.

TABLE 2

COMPARISON OF STOPPING DISTANCES FOR REGULAR AND STUDDED TIRES

Tire Combination	Required Distance (ft)		
	At 10 MPH	At 20 MPH	At 30 MPH
Four regular tires	5.9 (1.00)[a]	18.1 (1.00)[a]	44.6 (1.00)[a]
Two studded tires on rear	5.4 (0.92)[a]	19.5 (1.08)[a]	48.7 (1.09)[a]
Four studded tires	6.3 (1.07)[a]	22.2 (1.23)[a]	52.2 (1.17)[a]

[a] Ratios of indicated stopping distance to stopping distance for regular tires.

All of the stopping-distance tests were made on a dry portland cement concrete surface. Stops were made from speeds of 10, 20, and 30 mph. The tests were not extended to higher speeds because of the danger of the vehicle becoming unmanageable on the two-lane pavement of the test site. Three tire systems were used in the tests: (a) four studded tires; (b) two studded tires in the rear and standard tires in front; and (c) four standard tires. The test for each tire system and speed combination was repeated five times, a total of 45 test runs.

Results of the stopping-distance tests on dry concrete pavement are given in Table 2. For rear-mounted studded tires (regular tires in front), stopping distances ranged up to 9 percent greater than for regular tires; and for studded tires on all four wheels, stopping distances ranged up to 23 percent greater than for regular tires.

DISCUSSION

The surfaces of all three types of pavement were abraded by the studded winter tires for all conditions of testing. The starting and stopping tests produced the most serious abrasion, especially the rapid starts and emergency stops. The abrasion caused by the turning tests rated second, and the least amount occurred in the constant-speed tests.

During the rapid-start and emergency-stop tests, the tungsten carbide studs tended to cut four grooves in the pavement surface. These grooves corresponded to the four rows of studs in the tires. The studs tended to slip into the grooves on successive applications, and produced relatively deep grooves in the pavement early in the test. Successive applications tended to widen the grooves and eliminate ridges between the grooves.

Previous tests by other agencies have demonstrated that studded winter tires perform better on icy and hard-packed snow surfaces than either regular tires or standard snow tires. However, during these tests the regular tires exhibited more traction than the studded tires on dry pavement surfaces. Spinning the rear wheels during rapid start tests was more easily accomplished with studded tires than with regular tires. Stopping-distance tests on dry concrete pavement showed that up to 23 percent more stopping distance is required for a passenger car mounted on four studded tires than for a car with four regular tires. More spinning and sliding during starts and stops in emergency conditions with studded tires would tend to increase the damage done to pavements and at the same time decrease driver safety and vehicle control.

Available information on studded winter tires indicates that the tires are designed so that the rate of wear of the rubber tread and of the tungsten carbide studs would be the same. Under the conditions of these tests, however, the tire treads wore at a faster rate than the tungsten carbide studs. Measurements of the protrusion of the studs from the surface of the tread taken before and after the tests indicated that the average protrusion had increased by $^3/_{64}$ in. for both brands of tires. The average protrusion of the studs from the tread surface for the Goodyear tires was $^3/_{32}$ in. before testing and $^9/_{64}$ in. at the completion of testing. For the Allstate tires, the studs were flush with the tread surface before testing and protruded $^3/_{64}$ in. from the tread after testing. One of the Goodyear tires showing protrusion of the studs at the completion of the tests is shown in Figure 22.

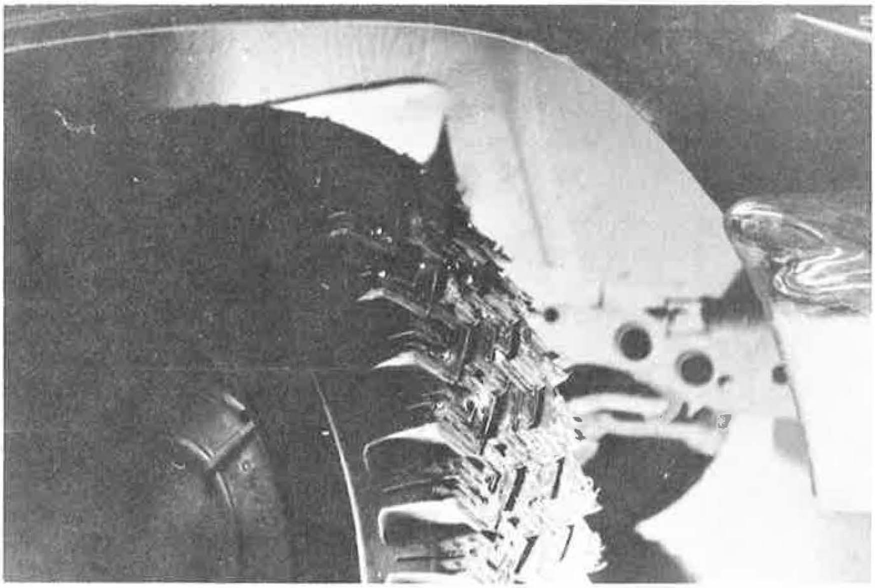

Figure 22. Goodyear tire showing protrusion of tungsten carbide studs at completion of testing.

Reports on tests of studded winter tires by other agencies have indicated loss of some of the studs during testing, and several agencies have expressed concern over the possible hazard of expulsion of studs at high speeds. During the tests at Ottawa, which involved fewer than 200 veh-mi of travel, four studs were lost from one tire and one stud was lost from each of two other tires.

SUMMARY

Advantages of Studded Tires

Tungsten-carbide studded tires permit better stopping and starting traction on ice and hard-packed snow than either regular tires or snow tires, but they do not provide as much traction as chains. The effectiveness of studded tires in improving traction on ice and hard-packed snow has been demonstrated adequately by numerous agencies both in this country and abroad. There is little question but that they are safer than either regular tires or snow tires on ice and hard-packed snow.

Disadvantages of Studded Tires

1. Studded tires have an abrasive effect on pavement surfaces. Unlike tire chains, studded tires can be expected to receive continuous use during the entire winter season as do ordinary snow tires. In a substantial part of the country, they can be expected to receive far more use on bare pavements than on ice- or snow-covered pavements. Studded tires are generally acknowledged to have an abrasive influence on pavement surfaces; the severity of the abrasive action is controversial. The results of exploratory tests involving up to 250 passages of typical studded winter tires mounted on passenger cars traveling on dry portland cement concrete, bituminous concrete, and bituminous surface treatment showed visible evidences of slight abrasion in normal driving and pronounced abrasion under emergency stop and start conditions. Abrasion depths up to $^1/_{16}$ in. were measured after 25 emergency stops followed by 25 quick starts on a concrete pavement. All pavements tested showed evidences of abrasion with the bituminous surface treatment showing the most pronounced abrasion. Tests were started with new tires in which the studs were flush with the tread surface or only slightly protruding. Measurements of stud protrusion before and after the tests showed an average increase in stud protrusion of $^3/_{64}$ in. caused by greater wear of the rubber. It can be surmised that even greater abrasion would have been recorded in the tests if the tires had been similarly worn before testing began. The test results suggest that abrasion caused by studded tires at locations of frequent stops and starts, or where frequent turning movements occur, would probably lead in some circumstances of heavy traffic to a need for special surface repairs.
2. Studded tires may be less safe on dry pavements than regular tires. Exploratory tests showed that on dry pavement up to 23 percent more stopping distance is needed for a vehicle mounted on four studded tires than for a vehicle with regular tires. Nine percent more stopping distance was needed when only rear-mounted studded tires were used.
3. Loss of studs from studded tires traveling at high speeds is a potential hazard. Various agencies have reported the loss of studs from tires in travel. During the Illinois tests, which involved fewer than 200 veh-mi of travel, four studs were lost from one tire, and one stud from each of two other tires.

Effects of Carbide Studded Tires On Roadway Surfaces

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Bureau of Research, Maryland State Roads Commission

The national interest aroused by the introduction of tungsten carbide studded tires to American and Canadian markets was shared by the Maryland State Roads Commission.

Preliminary trials with locked brakes showed that these tires would score pavement surfaces. The Commission therefore directed its Bureau of Research to prepare a proposal for field investigations of pavement surfaces, as affected by the use of these tires. The proposal was submitted to the U. S. Bureau of Public Roads and accepted for inclusion in the fiscal 1965 HPS-HPR Program.

Two test loops were chosen, one for trucks, one for passenger vehicles, each loop including both rigid and flexible type surfaces. Both front and rear tires of all test vehicles were equipped with studded tires. Ten thousand circuits of the test vehicles were made at each test loop. Reference markers were placed at numerous locations, and the amount of pavement wear was determined by depth gage measurements. Significant wear occurred at both test loops.

The limited tests described in this report show that a certain amount of damage was done to the highway pavement surfaces tested. It is considered undesirable to give unlimited authority for use of these tires until general observations have been made over a period of time.

•EUROPEAN tire manufacturers have experimented with metal insert types of snow tires for many years. An article in "Car and Driver" by Jan P. Norbye indicates that one manufacturer began his experimentation with metallic inserts well before World War II. Some phases of this development have included wire coils in the tread of the tire; shredded steel molded into the tread compound; removable treads which allow the placement of spikes for winter driving; and, finally, the incorporation of studs in the tire carcass.

During the autumn and winter of late 1962 and early 1963 studded tires appeared on American and Canadian markets, and considerable interest in them was aroused. Several national magazines published articles concerning their use and listed states where they were said to be legal or illegal.

A special maintenance session was held at the January 1965 Highway Research Board meeting to consider all aspects of the use of these tires. A representative of the Rubber Manufacturers' Association said that motor vehicle administrators or other officials of all the states had been contacted concerning the legality of studded tires, and presented the results of this inquiry. H. J. Rathfoot read a report by the AAA legal department indicating illegality in forty-one states, legality in two states, and doubtful in the remainder. Use of studs was reported to be allowed in West Germany, Switzerland,

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Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 45th Annual Meeting.

Figure 1. Preliminary test, sudden stops, rigid pavement.

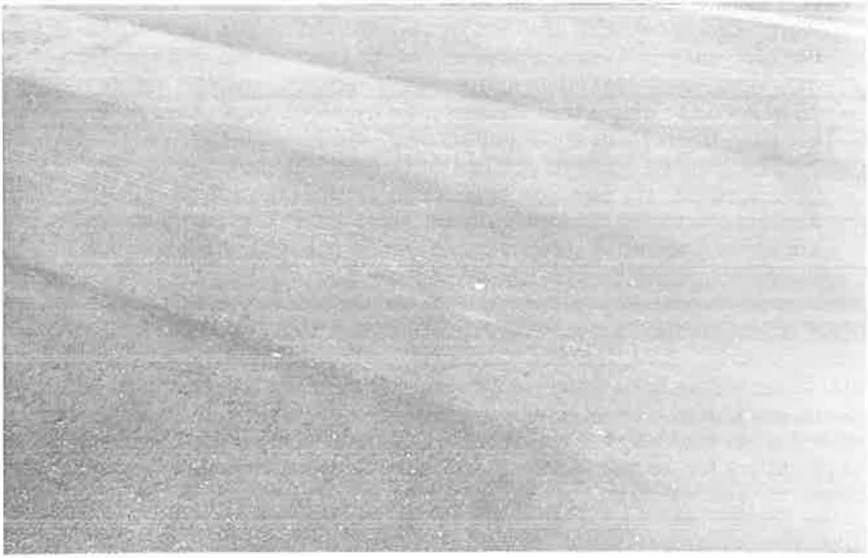

Figure 2. Preliminary test, sudden stops, flexible pavement.

Finland, Sweden, and possibly elsewhere in Europe, but prohibited in France and Luxembourg. Other matters discussed, although not conclusively, concerned ejection of studs at high speeds and damage to pavement surfaces.

Articles appeared in the Maryland newspapers commenting on use of the tires on Maryland's highways, in Baltimore City, and in adjoining states. As mentioned in one of the articles, the Motor Vehicles Department has the responsibility for determining what is, or is not, a snow tire, but the State Roads Commission has the power to ban from the highways any tire it determines is injurious to road surfaces. This power is

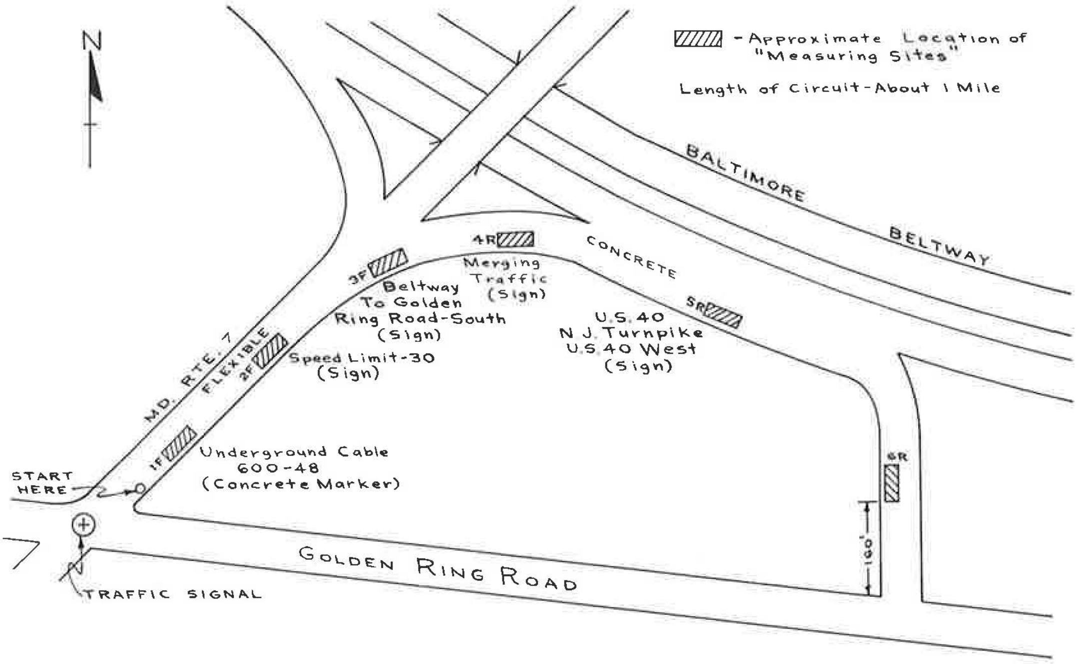

Figure 3. Truck test loop, Md. 7, between Golden Ring Rd. and Baltimore Beltway.

defined in Section 67, Article 89B of the Maryland Code, a portion of which reads as follows:

> No person shall operate upon any of the public roads or highways of this State, or of any county therein, any vehicle so constructed or equipped as to cause any unusual amount of damage to such highways; and no wagon, truck, road engine, traction engine or other vehicle having metal tires or treads shall be operated over or upon any such road or highway having upon the wheels any clamps, spikes, ribs or other devices which may cut into or injure the road surface, ...

PRELIMINARY INVESTIGATION

The Maryland State Roads Commission ordered a pair of Goodyear passenger-type snow tires with Suburbanite tread, equipped with tungsten carbide studs (described in detail later in the report). The tires were mounted on the rear wheels of the Commission's skid test car, a 1958 Chevrolet, and several sudden stops were made along Md. 3, south of Baltimore. Stops were made on both portland cement concrete and asphaltic-concrete surfaces (Figs. 1 and 2).

Although no attempt was made to measure the depths of the markings produced by the foregoing preliminary tests, it was felt that the scoring was significant. Maryland, along with many neighboring states, practices an extensive bare-pavement maintenance program during the winter snow and ice periods. In view of the fact that these extremely hard studs would be used most of the time on bare pavements, it was thought that further investigations into their effect on pavement surfaces should be conducted.

OBJECTIVE

The Commission and Chief Engineer directed the Bureau of Research to outline a practical test and submit a proposal to the U. S. Bureau of Public Roads suggesting a cooperative investigation as an addition to the state's fiscal 1965 HPS-HPR Program.

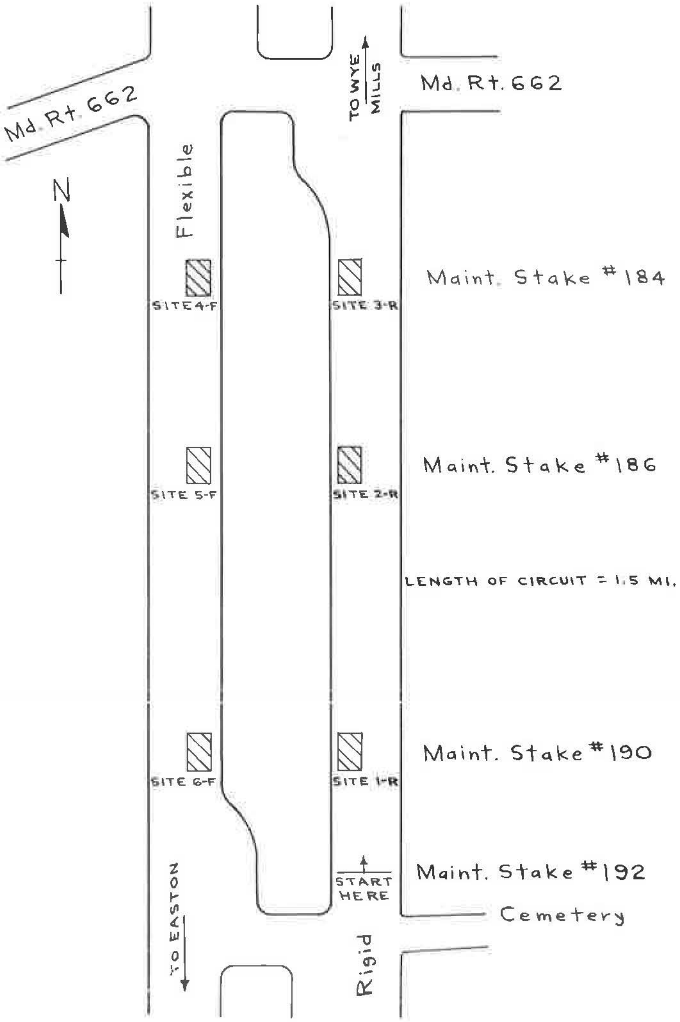

Figure 4. Passenger car test loop, US 50, between Easton and Wye Mills.

The proposal was submitted on January 28, 1965, and approved on March 1, 1965. This proposal noted that "the purpose of this investigation is to determine the effect of the passage of both trucks and passenger cars equipped with these (studded) tires on highway surfaces in this State."

FIELD INVESTIGATION

Test Loops and Measurement Sites

The proposal provided that the field tests would be conducted along two loops of the Maryland highway system, each of which would include both rigid and flexible pavements.

The truck test loop was selected along Md. 7 and the Baltimore Beltway about 10 mi east of Baltimore, and the passenger vehicle test loop was situated along US 50 about 6 mi north of Easton on the Eastern Shore.

The truck loop was about 1 mi in length (Fig. 3). Md. 7 is of flexible construction, and the Baltimore Beltway ramp is rigid.

The total length of the passenger vehicle loop is about 1½ mi (Fig. 4). The northbound roadway of this divided highway is of rigid construction, and the southbound road-

TABLE 1

COMPOSITION OF PAVEMENT

	US 50
Rigid Pavement:	9-in. reinforced cement concrete (A-3 local borrow) Completed: 5/47, contract T-67-1-281
Gravel aggregate:	from Warner Company, Morrisville, Leylestown, Bucks County, Pa.
Cement:	Keystone type I asphalt cut-back curing.
Flexible Pavement:	1-in. bituminous concrete PC-1-61 band (Md. Specs.) Completed: 10/31/61, contract T-144-8-220 3½-in. bituminous concrete P-2 band 12-in. sand aggregate base (3-4-in. layers, local borrow)
PC-1-61 band:	coarse agg.—D. M. Stoltzfus Stone, Cedar Hill, Pa. fine agg.—D. M. Stoltzfus Stone, Quarryville, Pa. Seaford Sand, Smithville, Md.
P-2 band:	coarse agg.—D. M. Stoltzfus Stone, Cedar Hill, Pa. D. M. Stoltzfus Stone, Talmadge, Pa. fine agg.—D. M. Stoltzfus Stone, Grey's Run, Pa. Seaford Sand, Smithville, Md.
Asphalt:	American Oil Co., 85-100 penetration.
	MD. 7 AND BELTWAY
Rigid Pavement:	9-in. reinforced cement concrete—min. 6-in. type II subbase Completed: 11/13/59 Subbase Warner Prop., North Point Road, Md.
Coarse agg.:	H. T. Campbell Stone, Texas, Md.
Sand:	H. T. Campbell, White Marsh, Md.
Cement:	medusa type I-A
Sites 1F and 2F:	1-in. bituminous concrete PC-1-59 band (Md. specs.) (resurfaced 5/61) ½-in. surface treatment 3-in. penetration macadam 5-in. waterbound macadam
PC-1-59 band:	coarse agg.—J. E. Baker Stone, Balto. Co., Md. fine agg.—H. T. Campbell Stone, Texas, Md. H. T. Campbell Sand, White March, Md.
Asphalt:	Lake asphalt, 85-100 penetration.
Site 3F:	1-in. bituminous concrete spec. B—surface course Completed: 11/13/59 2½-in. bituminous concrete spec. B—base course
Note:	Aggregates for the surface and base course bituminous concrete were the same as those used for the PC-1-59 band bituminous course of sites 1F and 2F. Prime coat 12-in. plant mix stabilized aggregate base course (3-4-in. layers) 4-in. type II subbase

way is flexible. Test vehicles used the median lane of each directional roadway. Table 1 gives age, thickness and material data for both loops.

Six measurement sites were selected along each loop so that detailed measurements of pavement wear could be made (Figs. 3 and 4). Along the truck loop 1F, 2F, and 3F are the flexible measurement sites, and 4R, 5R, and 6R are along the rigid pavement. For the passenger vehicle loop, 1R, 2R, and 3R are in rigid pavement areas, and 4F, 5F, and 6F are for flexible pavement wear measurement.

A typical measurement site for the truck loop is shown in Figure 5. The details for the layout at the passenger vehicle loop are nearly identical, the only difference being that the distance from centerline of lane to centerline of wheelpath is 30 in. The twenty reference markers at each measurement site were steel studs or nails driven into the pavement surface with an explosive charge. Inasmuch as each of the test loops was used by ordinary highway traffic as well as the test vehicles, some damage to the reference markers was anticipated. For this reason five transverse lines for measurement wear were provided at each site, with the hope that all sites would contain some significant records.

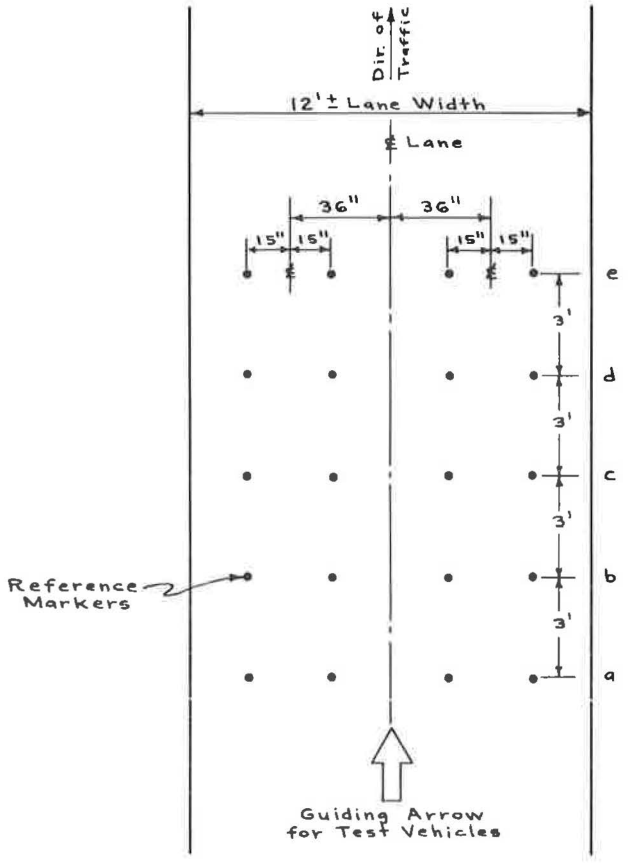

Figure 5. Typical measurement site, truck test loop.

Figure 6. Depth gage, Vernier method.

A steel straightedge was placed over each pair of reference markers, and measurements were recorded between the top of it and the pavement surface. Measurements were made before the test vehicles began their circuits and at approximately each 2,000 circuits until the 10,000 circuits of the test were completed. For each series of readings measurements were recorded at 1½-in. intervals by means of a depth gage (Fig. 6).

Figure 7. Truck tires, start of test.

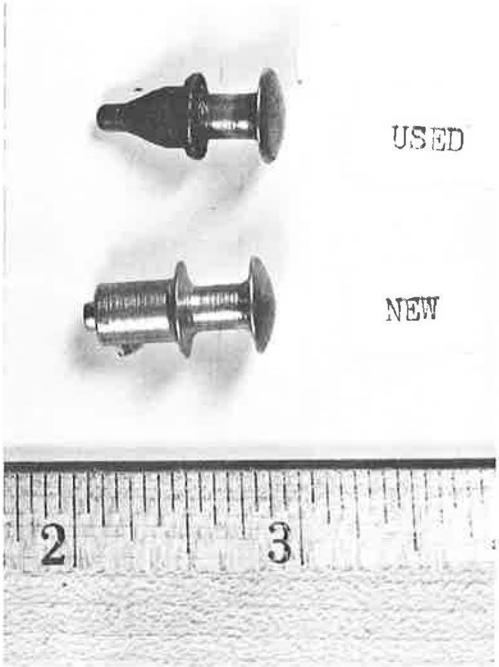

Figure 8. Carbide stud, truck tires.

Figure 9. Rear tires of passenger car, start of test.

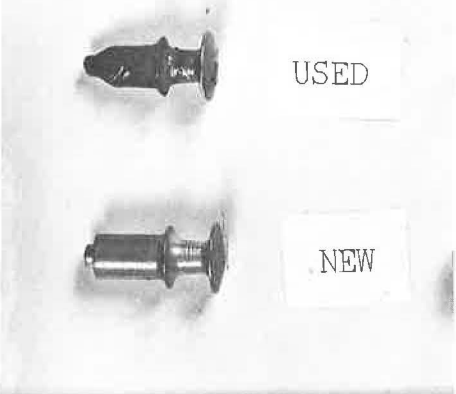

Figure 10. Carbide stud, passenger car tires.

TABLE 2

WEATHER CONDITIONS

Test Loop	Temperature (F)					Precipitation (in.)		Snow and Sleet (in.)	
	Avg. Max.	Avg. Min.	Avg.	Highest	Lowest	Greatest Day	Total	Max. Depth on Ground	Total
US 50—Car	52.4	31.9	42.2	67	18	1.21	4.09[a]	2.0	2.0
Md. 7 and Beltway—Truck	50.1	30.0	40.1	65	12	1.74	4.27[b]	4.0	9.5

[a] Based on 10 days.
[b] Based on 12 days.

Test Vehicles, Tires and Studs

Two test vehicles equipped with tungsten carbide studded tires on front and rear axles were used along each test loop.

The two trucks were International Loadstars, 1700, each loaded to a gross weight of about 23,000 lb, with a front-axle load of approximately 7,000 lb and a 16,000-lb rear-axle load. The trucks have two wheels on the front axle, four on the rear axle. Tires were Goodyear carbide studded, 900 × 20, 10-ply, tube-type, nylon case, Suburbanite treads; 110 tungsten carbide studs were used per tire (Figs. 7 and 8). During the test a total of sixteen such tires was used on the two vehicles. An experienced maintenance supervisor, present during the entire test, arranged for tire rotation to equalize wear. At the end of the test approximately 70 percent of the studs remained in these tires. Test trucks traversed this loop at about 40 mph.

The two passenger vehicles used for the US 50 test loop were a 1958 Chevrolet station wagon and a 1963 Ford sedan. The station wagon used 775 × 14 Goodyear carbide studded tires, tubeless, 4-ply, Suburbanite treads, with 104 carbide studs. The Ford sedan used 825 × 14 Goodyear carbide studded tires, tubeless, 4-ply, Suburbanite treads, also with 104 carbide studs (Figs. 9 and 10). Front and rear axle loads were approximately equal for each passenger vehicle, i.e., about 1,800 lb for the Ford sedan, and about 2,000 lb for the Chevrolet station wagon. A total of 18 passenger tires were used during the test, two sets of tires and a spare for each vehicle. At approximately 5,000 circuits both vehicles were equipped with a new set of tires, as only 20 percent of the carbide studs remained in the original tires. When the test was completed only 23 percent of the carbide studs remained in the second set of tires. Test passenger vehicles were driven at about 55 mph except at ends of loop where travel directions were reversed.

The local tire supplier indicated that all tire studs were placed after the molding process, probably by means of an air gun designed for this purpose.

Test Circuits

Vehicles and operating personnel were made available through the cooperation of the Commission's Bureau of Maintenance.

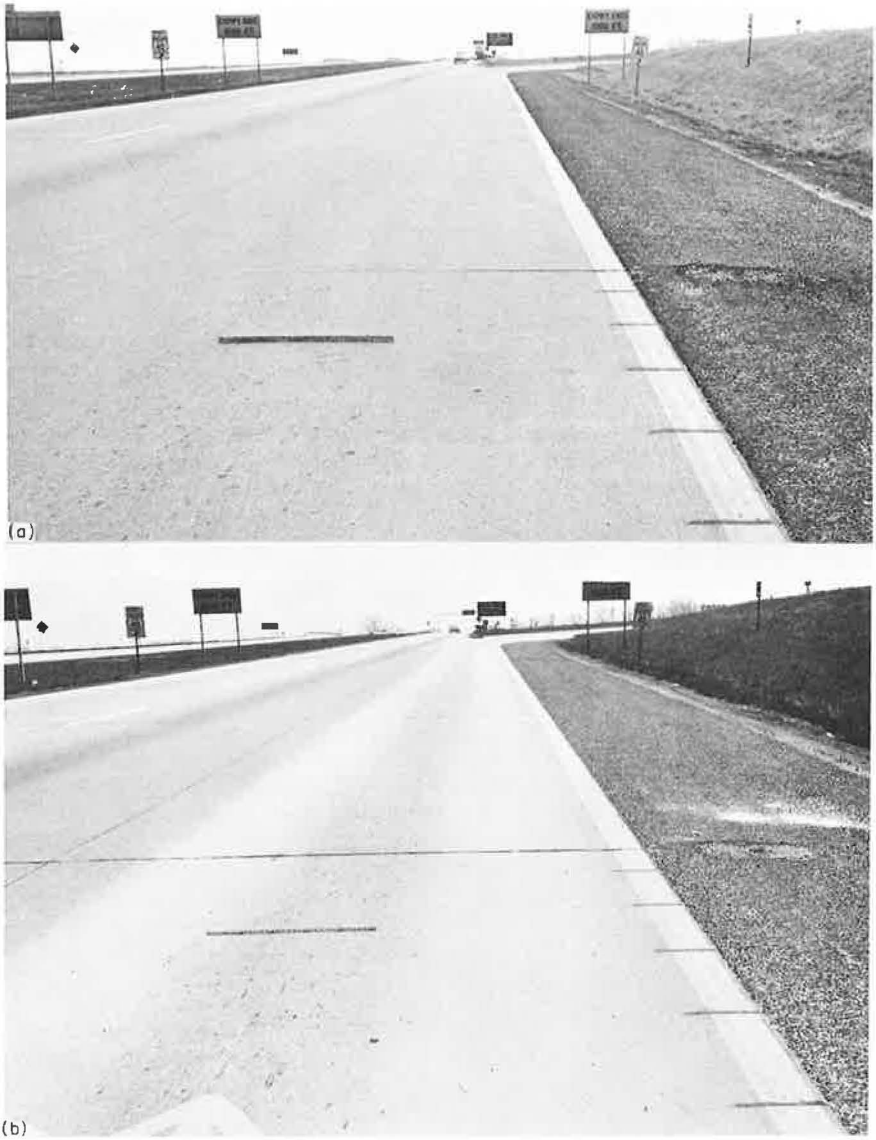

Figure 11. Truck test loop, rigid pavement (a) before test and (b) after test, Md. 7 and Baltimore Beltway.

Inasmuch as equipment and men would be needed for spring maintenance operations, the field test for this study was limited to a maximum of 10,000 circuits of each loop.

The actual field testing began in very late winter and was completed in early spring, during which time air temperature ranged from about 12 to 67 F. Detailed weather data are given in Table 2.

Measurements previously referred to were recorded at about 2,000 circuit intervals. The operation of test vehicles was similar to that for ordinary trucks and passenger vehicles using the highway. Although each measurement site included a conspicuous yellow guiding arrow, there was no attempt to slow down and exactly position the vehicle. The wear extended over the entire 30 in. between reference markers for each wheelpath.

Effect of the studs on the pavement surfaces was apparent after the first day of test circuits. Initially, the wear was more easily noticed on the rigid pavement surfaces.

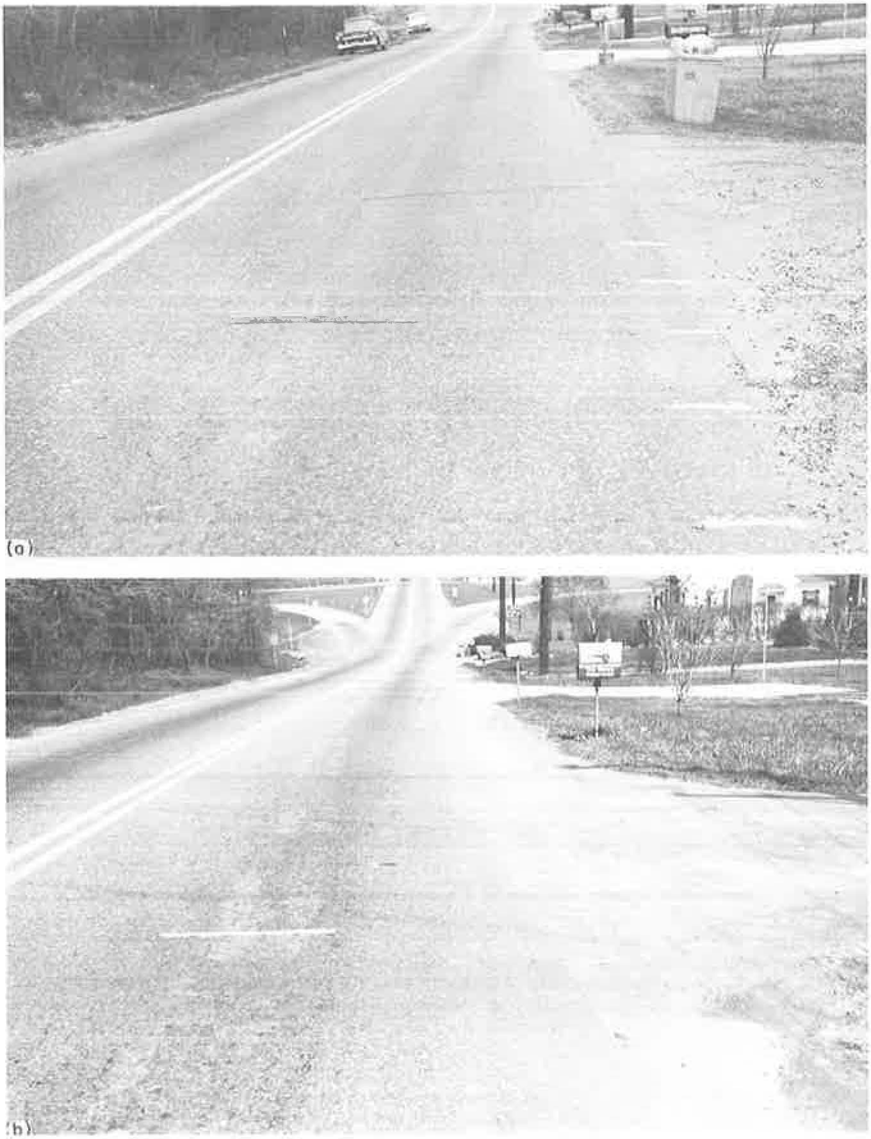

Figure 12. Truck test loop, flexible pavement (a) before test and (b) after test, Md. 7 and Baltimore Beltway.

Figure 11 shows the condition of the rigid pavement surface at beginning and end of the test for the Baltimore Beltway ramp subjected to truck test circuits. Figure 12 shows the flexible pavement along Md. 7 at the beginning and end of the same truck test.

ANALYSIS AND INTERPRETATION

The anticipated damage to a portion of the reference markers occurred, and in a few cases for reference marker pairs all 19 final readings were smaller than the initial ones, and obviously had to be discarded. Then initial and final readings for reference marker pairs were averaged, and where final averages were less than initial averages the data were discarded as not significant. Remaining were 58 percent of the total lines of observation on the passenger loop, and 52 percent on the truck loop, where data were considered significant, and actual pavement wear was at least the recorded amount.

TABLE 3

TRUCK TEST LOOP, MAXIMUM WEAR—MD. 7[a]

Meas. Site	Transv. Line	Point	Final Read. (in.)	Init. Read. (in.)	Max. Wear (in.)	Range of Max. Wear (in.)
1F	Oa	—	No significance		—	0.061
1F	Ob	9	2.091	2.030	0.061	
1F	Oc	—	No significance		—	
1F	Od	—	No significance		—	
1F	Oe	—	No significance		—	
1F	Ia	4	2.290	2.233	0.057	0.057-0.117
1F	Ib	9	2.357	2.287	0.070	
1F	Ic	—	No significance		—	
1F	Id	10	2.318	2.219	0.099	
1F	Ie	4	2.295	2.178	0.117	
2F	Oa	—	No significance		—	0.068-0.084
2F	Ob	—	No significance		—	
2F	Oc	—	No significance		—	
2F	Od	11	2.160	2.092	0.068	
2F	Oc	7	2.205	2.121	0.084	
2F	Ia	11	2.330	2.238	0.092	0.076-0.174
2F	Ib	12	2.360	2.284	0.076	
2F	Ic	15	2.410	2.236	0.174	
2F	Id	—	No significance		—	
2F	Ie	—	No significance		—	
3F	Oa	18	2.258	2.165	0.093	0.050-0.093
3F	Ob	—	No significance		—	
3F	Oc	8	2.310	2.260	0.050	
3F	Od	—	No significance		—	
3F	Oe	12	2.280	2.226	0.054	
3F	Ia	—	No significance		—	0.084-0.135
3F	Ib	8	2.256	2.143	0.113	
3F	Ic	10	2.302	2.167	0.135	
3F	Id	7	2.306	2.198	0.108	
3F	Ie	3	2.320	2.236	0.084	
4R	Oa	—	No significance		—	0.022
4R	Ob	—	No significance		—	
4R	Oc	—	No significance		—	
4R	Od	—	No significance		—	
4R	Oe	6	2.267	2.245	0.022	
4R	Ia	—	No significance		—	0.068-0.119
4R	Ib	11	2.351	2.256	0.095	
4R	Ic	11	2.371	2.252	0.119	
4R	Id	8	2.207	2.114	0.093	
4R	Ie	9	2.288	2.220	0.068	
5R	Oa	—	No significance		—	0.038-0.039
5R	Ob	—	No significance		—	
5R	Oc	—	No significance		—	
5R	Od	13	2.198	2.159	0.039	
5R	Oe	4	2.117	2.079	0.038	
5R	Ia	10	2.270	2.224	0.046	0.046-0.068
5R	Ib	—	No significance		—	
5R	Ic	10	2.309	2.241	0.068	
5R	Id	—	No significance		—	
5R	Ie	14	2.215	2.164	0.051	
6R	Oa	—	No significance		—	
6R	Ob	—	No significance		—	
6R	Oc	—	No significance		—	
6R	Od	—	No significance		—	
6R	Oe	—	No significance		—	
6R	Ia	11	2.318	2.268	0.050	0.048-0.170
6R	Ib	—	No significance		—	
6R	Ic	16	2.548	2.378	0.170	
6R	Id	7	2.161	2.113	0.048	
6R	Ie	18	2.421	2.342	0.079	

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[a] Depth gage method.

TABLE 4

PASSENGER CAR TEST LOOP, MAXIMUM WEAR—US 50[a]

Meas. Site	Transv. Line	Point	Final Read. (in.)	Init. Read. (in.)	Max. Wear (in.)	Range of Max. Wear (in.)
1R	Oa	15	2.286	2.262	0.024	
1R	Ob	10	2.313	2.300	0.013	0.013-0.026
1R	Oc	14	2.149	2.123	0.026	
1R	Od	—	No significance		—	
1R	Oe	—	No significance		—	
1R	Ia	—	No significance		—	
1R	Ib	2	2.124	2.101	0.023	
1R	Ic	7	2.090	2.074	0.016	0.016-0.023
1R	Id	—	No significance		—	
1R	Ie	—	No significance		—	
2R	Oa	—	No significance		—	
2R	Ob	—	No significance		—	
2R	Oc	—	No significance		—	
2R	Od	—	No significance		—	
2R	Oe	—	No significance		—	
2R	Ia	—	No significance		—	
2R	Ib	—	No significance		—	
2R	Ic	—	No significance		—	
2R	Id	—	No significance		—	
2R	Ie	—	No significance		—	
3R	Oa	18	2.149	2.122	0.027	
3R	Ob	—	No significance		—	
3R	Oc	—	No significance		—	0.026-0.027
3R	Od	8	2.226	2.200	0.026	
3R	Oe	—	No significance		—	
3R	Ia	—	No significance		—	
3R	Ib	1	2.312	2.260	0.052	
3R	Ic	—	No significance		—	0.024-0.052
3R	Id	9	2.167	2.116	0.051	
3R	Ie	7	2.278	2.254	0.024	
4F	Oa	—	No significance		—	
4F	Ob	—	No significance		—	
4F	Oc	2	2.310	2.249	0.061	0.035-0.061
4F	Od	—	No significance		—	
4F	Oe	6	2.322	2.287	0.035	
4F	Ia	11	2.343	2.315	0.028	
4F	Ib	2	2.329	2.281	0.048	0.028-0.057
4F	Ic	12	2.326	2.278	0.048	
4F	Id	9	2.324	2.267	0.057	
4F	Ie	—	No significance		—	
5F	Oa	3	2.298	2.191	0.107	
5F	Ob	3	2.264	2.207	0.057	
5F	Oc	15	2.370	2.314	0.056	0.056-0.107
5F	Od	10	2.284	2.177	0.107	
5F	Oe	8	2.287	2.182	0.105	
5F	Ia	5	2.334	2.286	0.048	
5F	Ib	9	2.346	2.273	0.073	0.041-0.083
5F	Ic	12	2.370	2.293	0.077	
5F	Id	8	2.440	2.357	0.083	
5F	Ie	14	2.385	2.344	0.041	
6F	Oa	13	2.342	2.281	0.061	
6F	Ob	4	2.409	2.340	0.069	
6F	Oc	—	No significance		—	0.061-0.089
6F	Od	8	2.251	2.180	0.071	
6F	Oe	9	2.339	2.250	0.089	
6F	Ia	13	2.385	2.332	0.053	
6F	Ib	9	2.410	2.330	0.081	
6F	Ic	8	2.417	2.319	0.098	0.053-0.098
6F	Id	11	2.343	2.284	0.059	
6F	Ie	9	2.350	2.301	0.049	

[a] Depth gage method.

TABLE 5

TRUCK TEST LOOP, AVERAGE WEAR—MD. 7[a]

Meas. Site	Transv. Line	Avg. Init. Read. (in.)	Avg. Final Read. (in.)	Avg. Wear (in.)	Avg. Wear, Wheelpath (in.)	Avg. Wear, Meas. Site (in.)	Avg. Wear at All Meas. Sites (in.)
1F	Ob	0.066	0.081	0.015	0.015	0.025	0.031 (flexible)
1F	Ia	0.255	0.275	0.020	0.034		
1F	Ib	0.285	0.305	0.020			
1F	Id	0.214	0.247	0.033			
1F	Ie	0.173	0.238	0.065			
2F	Od	0.117	0.143	0.026	0.030	0.033	
2F	Oe	0.136	0.171	0.035			
2F	Ia	0.233	0.260	0.027	0.037		
2F	Ib	0.305	0.320	0.015			
2F	Ic	0.290	0.359	0.069			
3F	Oa	0.200	0.227	0.027	0.014	0.035	
3F	Oc	0.295	0.296	0.001			
3F	Oe	0.223	0.237	0.014			
3F	Ib	0.192	0.256	0.064	0.057		
3F	Ic	0.183	0.240	0.057			
3F	Id	0.202	0.259	0.057			
3F	Ie	0.203	0.254	0.051			
4R	Oe	0.226	0.227	0.001	0.001	0.020	0.030 (rigid)
4R	Ib	0.262	0.301	0.039	0.040		
4R	Ic	0.244	0.289	0.045			
4R	Id	0.118	0.156	0.038			
4R	Ie	0.233	0.271	0.038			
5R	Od	0.217	0.223	0.006	0.011	0.020	
5R	Oe	0.118	0.134	0.016			
5R	Ia	0.234	0.256	0.022	0.030		
5R	Ic	0.250	0.293	0.043			
5R	Ie	0.177	0.202	0.025			
6R	None at OWP					0.051	
6R	Ia	0.286	0.308	0.022	0.051		
6R	Ic	0.322	0.432	0.110			
6R	Id	0.148	0.177	0.029			
6R	Ie	0.267	0.310	0.043			

[a] Depth gage method.

TABLE 6

PASSENGER CAR TEST LOOP, AVERAGE WEAR—US 50[a]

Meas. Site	Transv. Line.	Avg. Init. Read. (in.)	Avg. Final Read. (in.)	Avg. Wear (in.)	Avg. Wear, Wheelpath (in.)	Avg. Wear, Meas. Site (in.)	Avg. Wear, All Meas. Sites (in.)
1R	Oa	0.247	0.260	0.013	0.006	0.008	0.009 (rigid)
1R	Ob	0.299	0.300	0.001			
1R	Oc	0.166	0.171	0.005			
1R	Ib	0.114	0.118	0.004	0.011		
1R	Ic	0.249	0.267	0.018			
2R	None at OWP and IWP						
3R	Oa	0.138	0.152	0.014	0.012	0.010	
3R	Od	0.224	0.235	0.011			
3R	Ib	0.204	0.209	0.005	0.008		
3R	Id	0.158	0.165	0.007			
3R	Ie	0.229	0.240	0.011			
4F	Oc	0.276	0.282	0.006	0.013	0.011	0.020 (flexible)
4F	Oe	0.262	0.283	0.021			
4F	Ia	0.312	0.319	0.007	0.010		
4F	Ib	0.304	0.317	0.013			
4F	Ic	0.255	0.265	0.010			
4F	Id	0.279	0.290	0.011			
5F	Oa	0.281	0.312	0.031	0.030	0.028	
5F	Ob	0.232	0.261	0.029			
5F	Oc	0.292	0.323	0.031			
5F	Od	0.186	0.217	0.031			
5F	Oe	0.227	0.253	0.026			
5F	Ia	0.328	0.358	0.030	0.026		
5F	Ib	0.291	0.312	0.021			
5F	Ic	0.303	0.330	0.027			
5F	Id	0.345	0.385	0.040			
5F	Ie	0.334	0.346	0.012			
6F	Oa	0.323	0.345	0.022	0.018	0.021	
6F	Ob	0.356	0.380	0.024			
6F	Od	0.195	0.210	0.015			
6F	Oe	0.258	0.270	0.012			
6F	Ia	0.348	0.366	0.018	0.024		
6F	Ib	0.332	0.353	0.021			
6F	Ic	0.328	0.366	0.038			
6F	Id	0.285	0.318	0.033			
6F	Ie	0.312	0.321	0.009			

[a] Depth gage method.

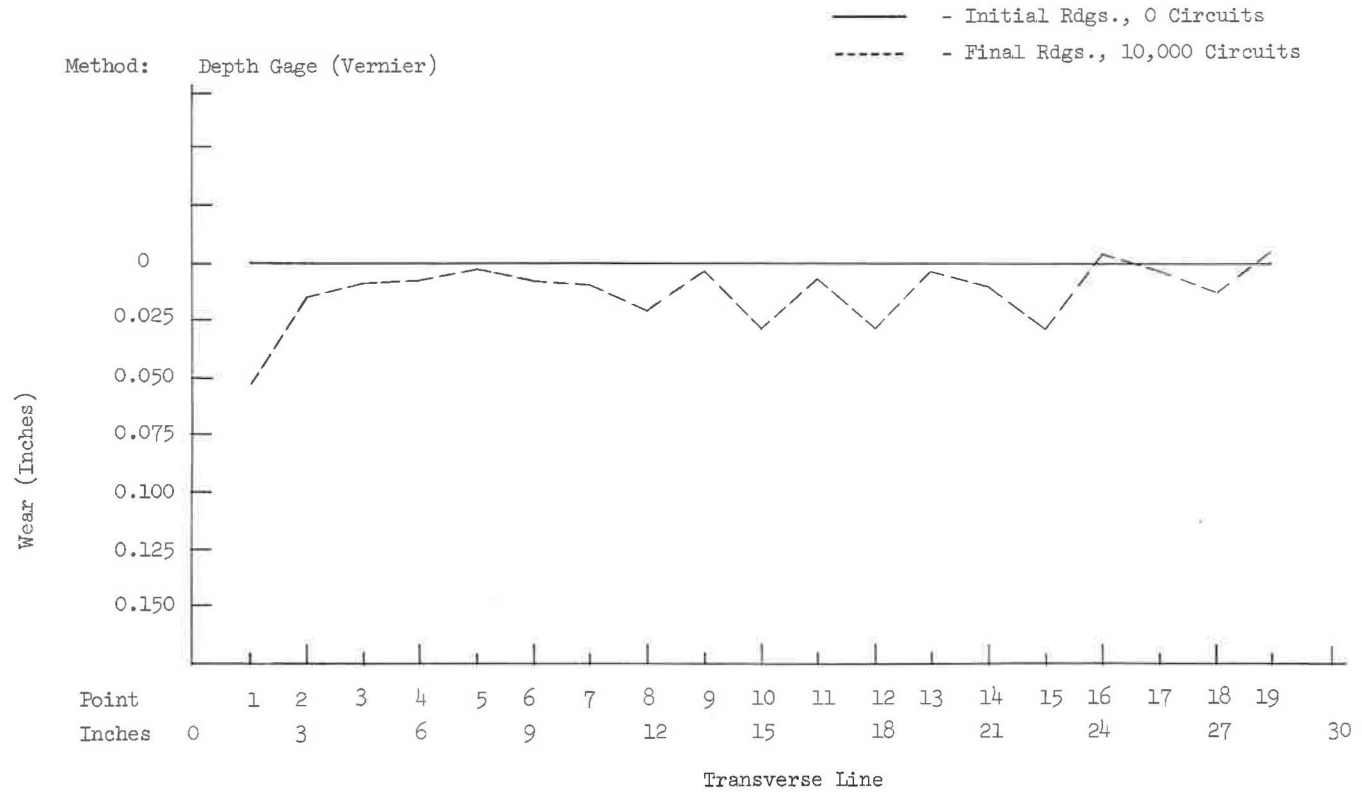

Figure 13. Passenger cars, transverse profile, US 50, site 3R, line lb.

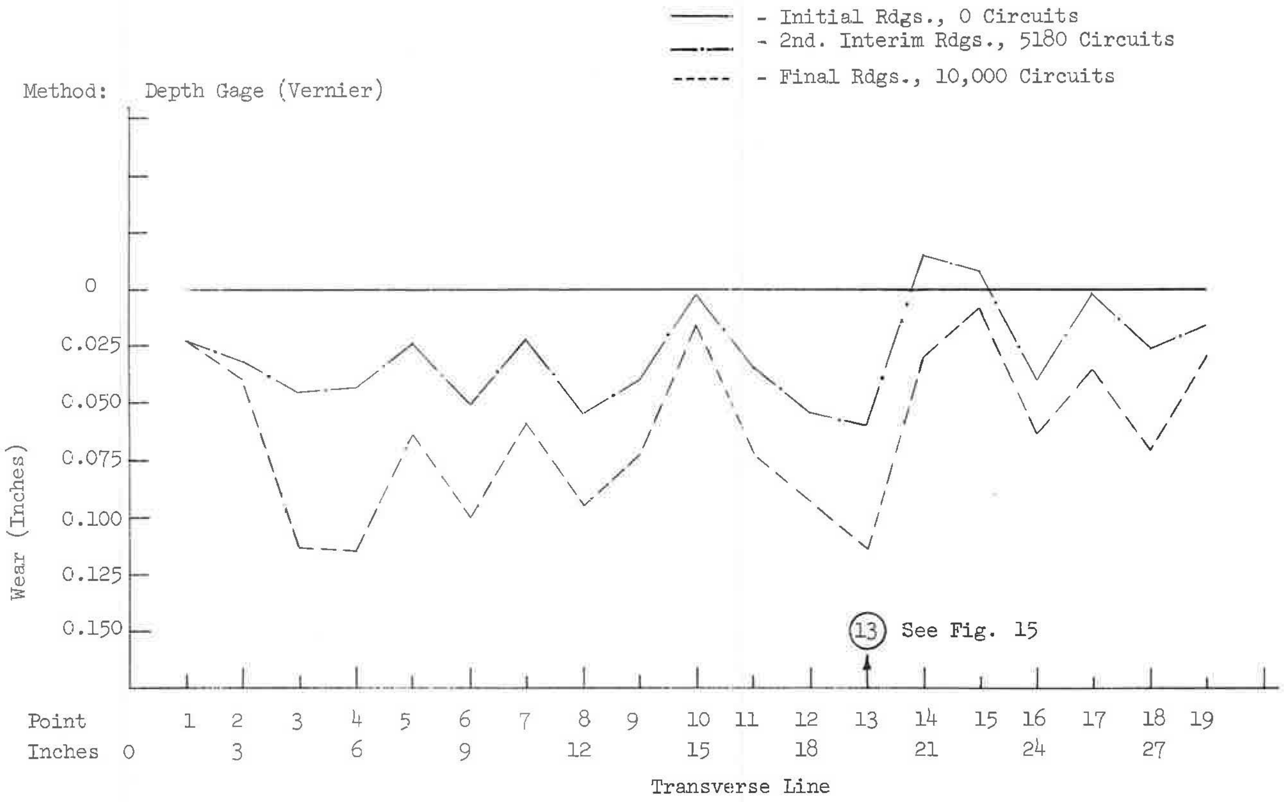

Figure 14. Trucks, transverse profile, Md. 7 and Baltimore Beltway, site 1F, line le.

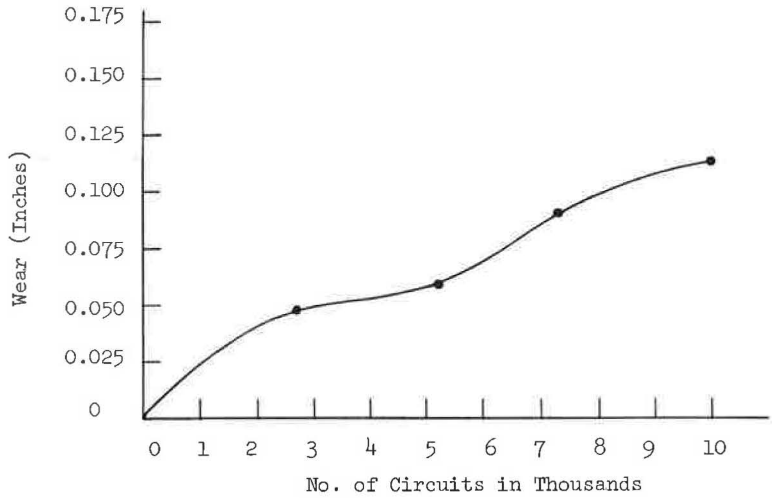

Figure 15. Trucks, rate of wear, Md. 7 and Baltimore Beltway, site 1F, line 1e, point No. 13.

Tables 3 and 4 give all transverse lines (between reference marker pairs) at all measurement sites and indicate where data were not considered significant. "Point" in the third column of the tables refers to the $1\frac{1}{2}$-in. increments between reference markers where measurements were observed. In all cases the point of maximum wear was selected for presentation.

The range of maximum wear is as follows:

	Passenger Vehicle Test Loop	Truck Test Loop
Flexible	0.028 in.-0.107 in.	0.050 in.-0.174 in.
Rigid	0.013 in.-0.052 in.	0.022 in.-0.170 in.

Tables 5 and 6 show average wear along each significant transverse line.

Average wear is the following:

	Passenger Vehicle Test Loop	Truck Test Loop
Flexible	0.020 in.	0.031 in.
Rigid	0.009 in.	0.030 in.

For the passenger car loop the wear at each significant transverse line at the end of test was plotted (Fig. 13). In the case of the truck loop, where wear was greater, the graphs show the wear at about midpoint as well as at the completion of the field test (Fig. 14). Figure 15 shows the rate of wear which occurred to the pavement surface at one of the points in Figure 14.

The truck loop included two measurement sites on 8- to 10-deg curvature; average wear for the two is as follows:

	IWP Avg. Wear	OWP Avg. Wear
Measurement site 3F	0.057 in.	0.014 in.
Measurement site 4R	0.040 in.	0.001 in.

The inner wheelpath (IWP) is the outside of curve and the increased wear in this path is no doubt due to the curving alignment. This may be indicative of wear which would occur from these tires on interchange ramps.

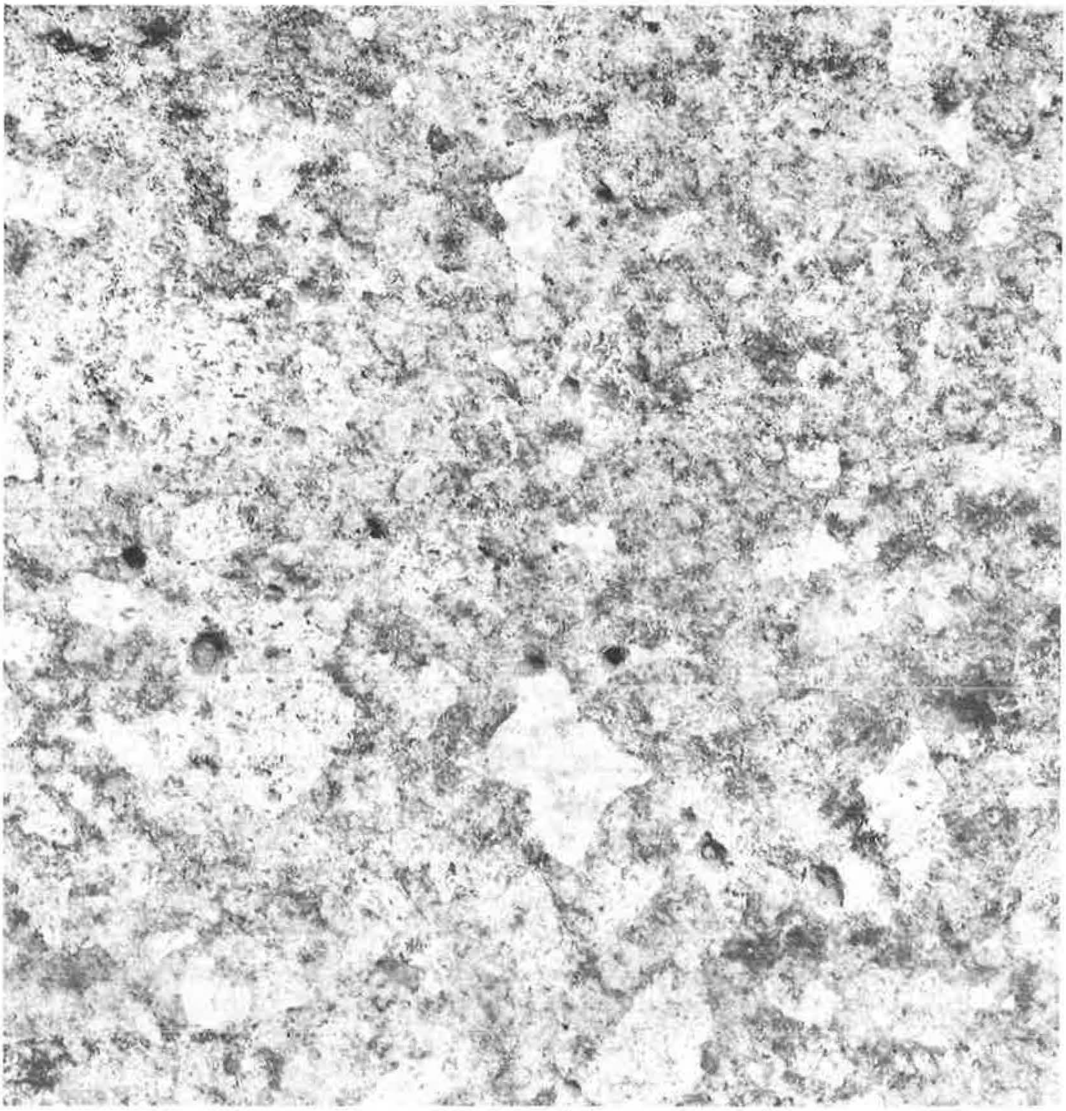

Figure 16. Inner wheelpath on curved ramp, exposed aggregate, end of test, Md. 7 and Baltimore Beltway.

Another curve of about the same degree occurs on this same ramp, but not at a measurement site. Greatly increased wear was experienced along the outside of curve; the surface is pock-marked by the passage of the test tires (Fig. 16).

An attempt was made to interpret the significance of the 10,000 test circuits in relation to actual traffic. The Commission's Traffic Bureau indicated that at the time of the field test the ADT for the northbound (rigid) roadway of US 50 was 3,484, and for the southbound (flexible) roadway it was 3,282. Passenger test vehicles used this loop. Assuming 90 percent of this traffic to be passenger cars, and 10 percent of these passenger cars to use carbide studded tires, 314 daily vehicles would use the rigid pavement, and 295 would use the flexible pavement. Thus, under the foregoing assumptions, the 10,000 circuits are approximately equivalent to 30 days of ordinary passenger car usage, or about one-fourth of a snow tire season in this area of Maryland.

The Traffic Bureau also furnished us with an ADT of 9,750 for the month of June 1964, along Md. 7, the truck test vehicle loop. This same traffic has been considered for all portions of the loop. The directional distribution is 55 percent. Assuming 10 percent of the traffic to be trucks, and 10 percent of the trucks to be equipped with carbide studded tires, we arrive at 54 trucks daily using the roadways of this loop. For these assumptions, the test circuits were equivalent to 185 days of use by the trucks using these roads and ramps. If the trucks are assumed to operate 26 days per month, these 185 days would be equivalent to about 1.8 of the usual snow tire season.

We do not feel that we could confidently add the truck loop wear and passenger loop wear and report it for combined wear to be expected on a 9,000 to 10,000 ADT facility; we would hesitate to multiply the passenger loop wear by four and report it as a season's wear for US 50; and, finally, we would not at this time attempt any straight-line comparisons between equivalent days for test trucks and test passenger vehicles. Although rates-of-wear curves did show a tendency to level off, it is quite possible that an accelerated upward trend might develop in the second or third 10,000 circuits, had they been made.

SUMMARY OF OBSERVATIONS AND TEST RESULTS

1. Significant wear was observed at both test loops, and for both pavement surface types.
2. Wear along curves and at areas of frequent braking can be considerably greater than the magnitude of the wear occurring along tangent alignment.
3. The number of test circuits was insufficient to allow forward projection of the rate-of-wear curves.
4. For future field tests of this type we would advise the use of reference markers set below the surface of the pavements.
5. For the surfaces tested, pavement wear due to truck test vehicles was greater than the pavement wear due to passenger test vehicles.
6. The investigators feel that considerable damage might be done to both rigid and flexible surfaces, for several reasons, if great numbers of passenger cars and trucks equipped with studded tires should use a particular highway.
7. The limited tests described in this report showed that a certain amount of damage has been done to the highway pavement surfaces tested. We would consider it undesirable to give unlimited authority for use of these tires until general observations have been made over a period of time.

ACKNOWLEDGMENTS

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