Preliminary Studies of Effect of Studded Tires on Highway Pavements

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•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.

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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.

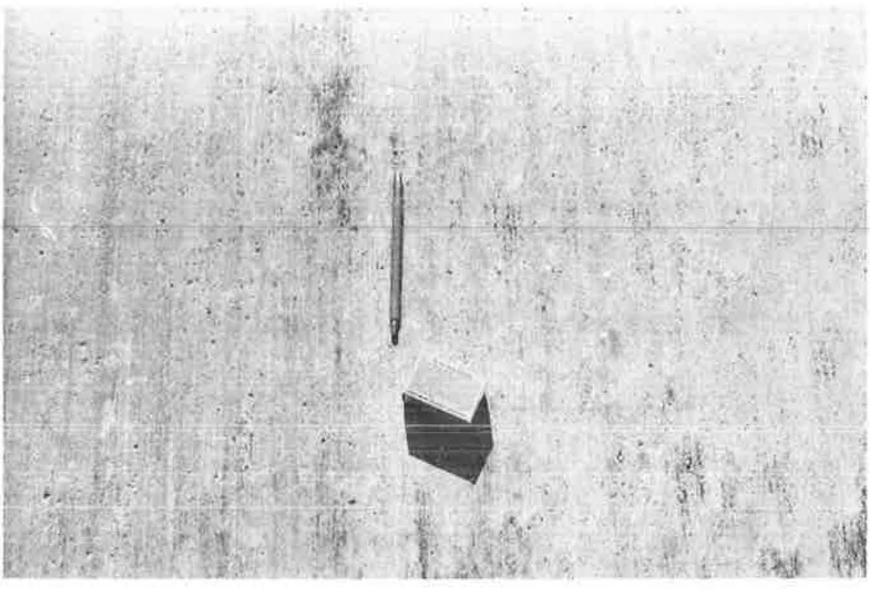

Figure 6. Surface of concrete after 310 panic stops.

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.

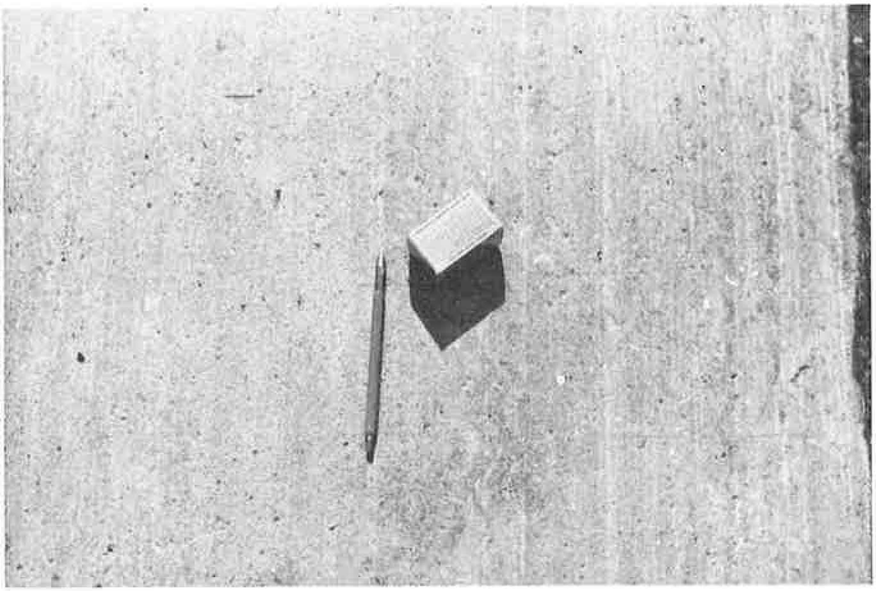

Figure 7. Surface of concrete after 310 rapid starts.

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.

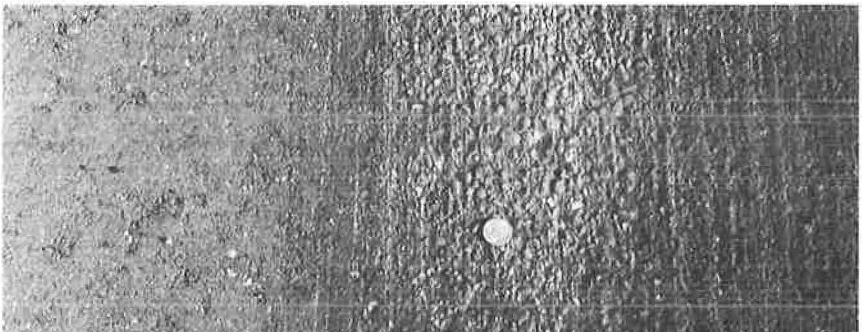

Figure 10. Bituminous surface after 210 panic stops.

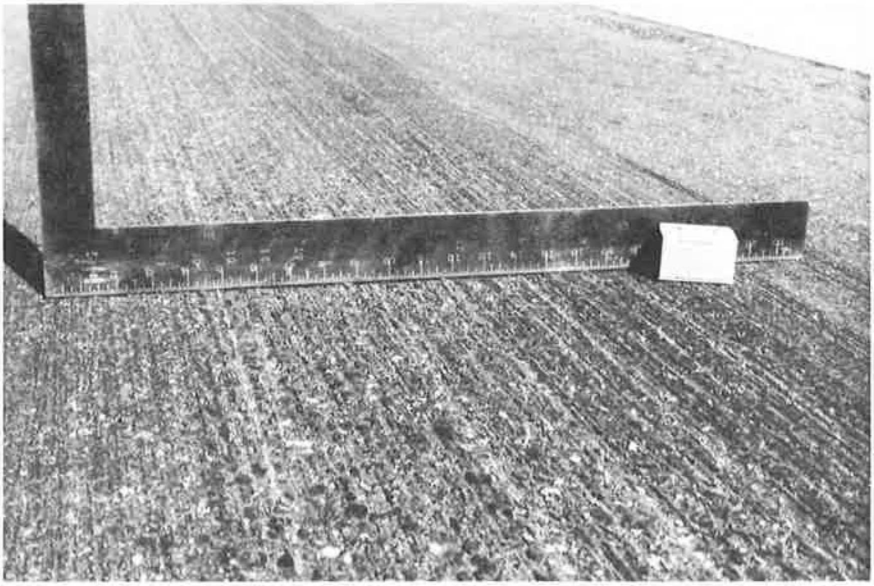

Figure 11. Bituminous surface after 310 panic stops.

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

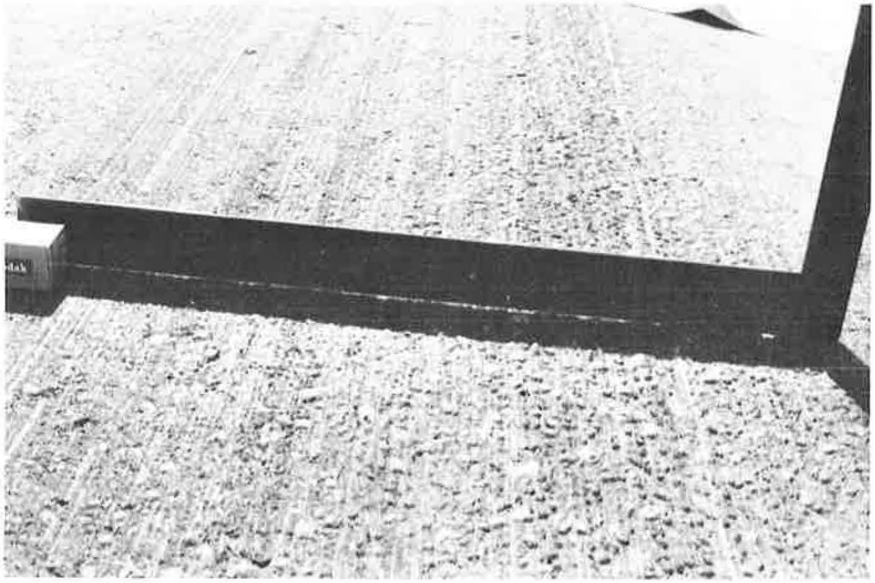

Figure 12. Bituminous surface after 310 panic stops.

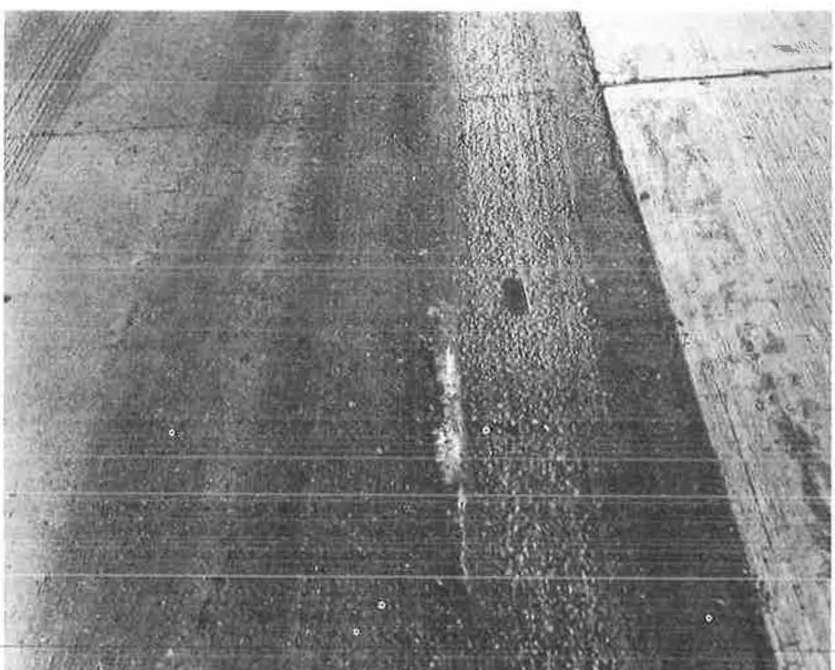

Figure 13. Bituminous surface after 210 rapid starts.

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.

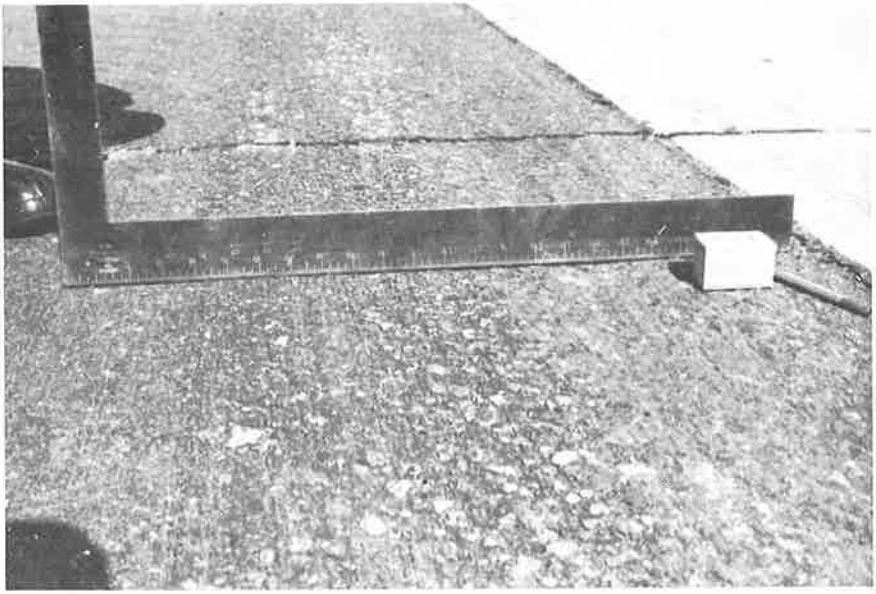

Figure 14. Bituminous surface after 310 rapid starts.

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.

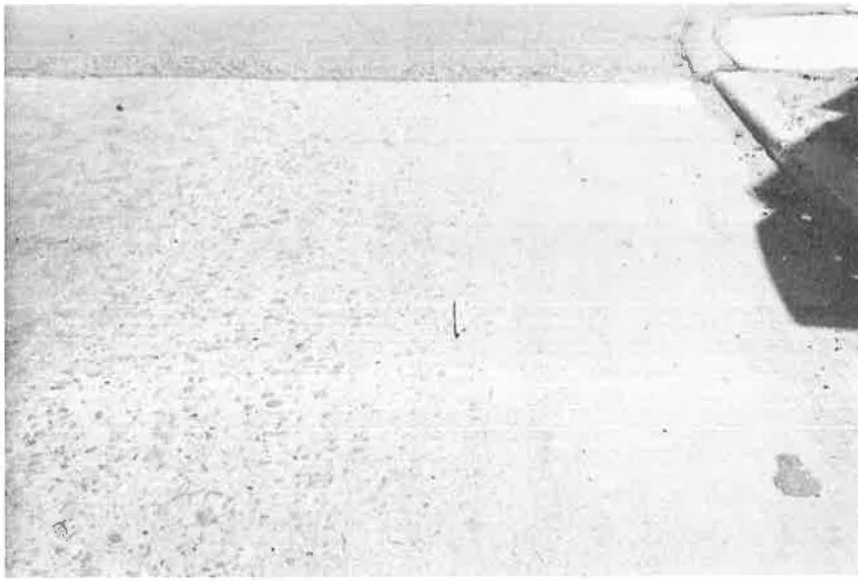

Figure 16. Condition of concrete surface at a high volume intersection.

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.

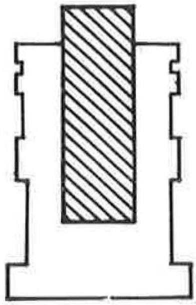

Figure 17. Cross-section of plastic encasement type stud, scale approximately 3X actual size.

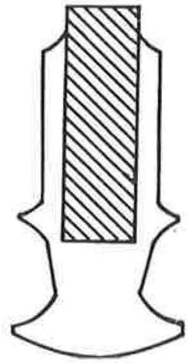

Figure 18. Cross-section of steel encasement type stud, scale approximately 3X actual size.

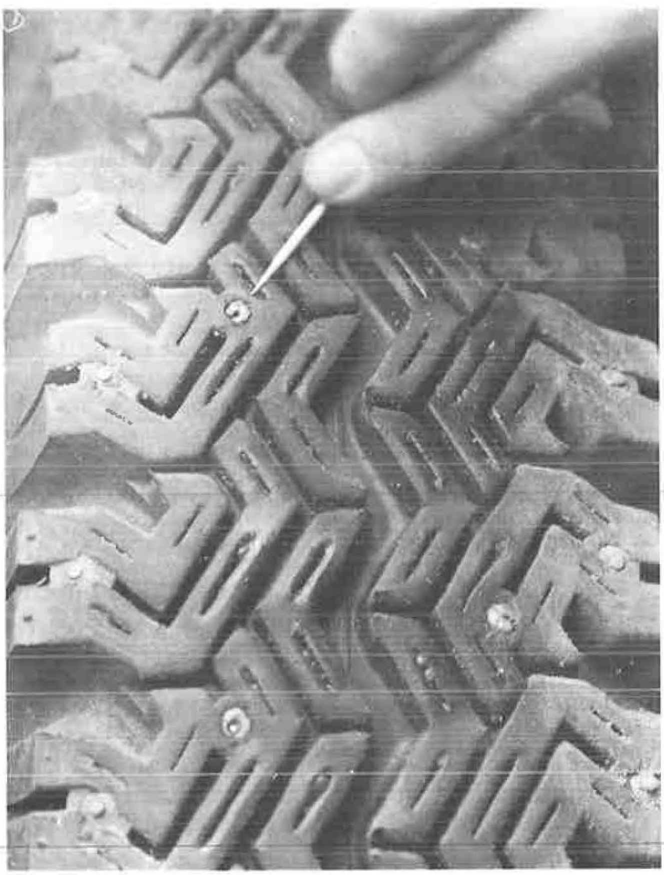

Figure 19. Condition of plastic encasement type studs after 21 series of stops and starts.

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.

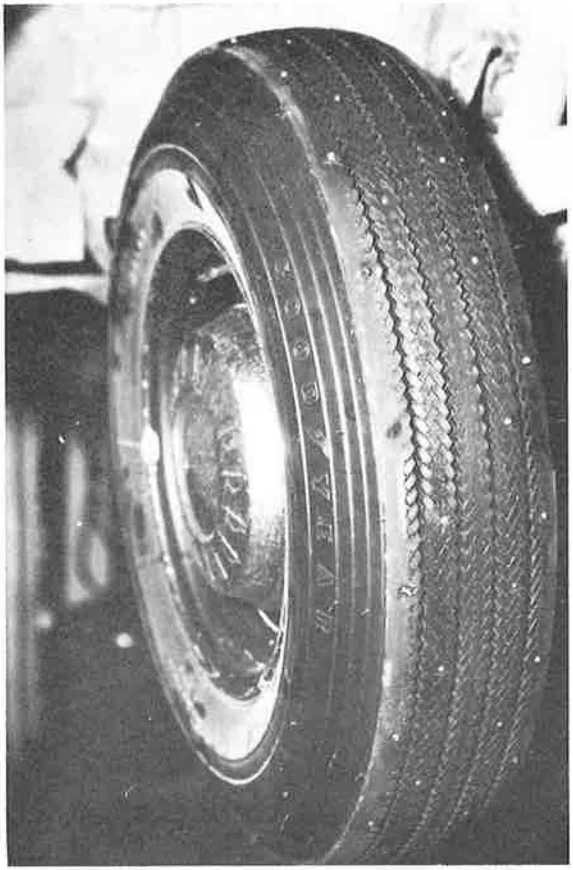

Figure 20. Condition of steel encasement type studs after 21 series of stops and starts.

Installation of Studs in Tires

The studs were inserted into holes in the tires by an air pressure gun. These holes, which were approximately $\frac{1}{8}$ in. in diameter by $\frac{1}{2}$ 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 $2\frac{1}{8}$ to $3\frac{5}{16}$ in. in the inner rows and from $1\frac{3}{16}$ to $1\frac{11}{16}$ 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 $^1/_4$ to $^3/_8$ 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.