NEW TIRE-STUD DEVELOPMENTS

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Although they offer snowbelt motorists substantial improvement of vehicle control on icy roads, studded tires have been attacked with increasing vigor by highway officials for their contribution to road wear. Tests of some recently developed tire-stud designs show promise that the safety and convenience factors of studded tires can be retained—but with a considerable reduction in the amount of road wear caused by their use. In addition to a reduction in weight and minor dimensional changes, most of these new tire studs are designed in such a way that the carbide pin will move farther into the stud body if, at any time, the protrusion of the stud from the tire exceeds a critical limit. (The greater the protrusion is, the greater the impact force is; and it is high-impact force that causes the road wear.) With their built-in protrusion-adjustment capability, the new tire studs maintain nearly uniform protrusion throughout their lifetime. Their ability to do so is unaffected by differences in wear resistance of various rubber compounds, driving speeds, or road surfaces traveled. Tires fitted with these new studs show an increase of 75 percent in coefficient of friction on smooth ice as compared to identical tires without studs. Coefficient of friction decreases only about 5 percent with such studded tires on bare concrete (cement) roads. No difference at all in performance between studded and unstudded tires has been found on bare bituminous pavement, dry or wet.

•USE of studded tires during the winter season has become increasingly popular in areas where roads are frequently covered with ice or snow. Based on sales figures and local surveys, studded tires were used last winter on approximately 40 percent of all passenger cars in Canada, the northern part of the United States, and central Europe. It has been reported that in the winter of 1970-1971 more than 70 percent of all vehicles in Scandinavia were equipped with 4 studded tires.

Use of studded tires on trucks, for the most part, has been limited to Scandinavia and France. In most other countries, the use of studded truck tires has been restricted by law or has not been promoted by the tire-stud industry because of accelerated road wear. It has become evident, especially in areas with high traffic volume, that studded tires are an additional road-wear factor. This was confirmed in field measurements, road tests with controlled driving programs, and laboratory tests (1 through 34).

Most of the research clearly indicates that additional maintenance is required on roads that have a heavy traffic volume and a great number of cars equipped with studded tires. However, on roads that have a relatively light traffic volume, resurfacing is not required any earlier than would otherwise be necessary. It is significant that by far the majority of U.S. highways carry a relatively light traffic volume. Our heavily traveled Interstate routes, expressways, and major arteries within cities represent only a small part of the total mileage in our road system. Most reports also show that the wear resistance of different pavement types varies substantially and that pavements can be improved to offer substantially more wear resistance.

Faced with a possible legal ban of its product, the tire-stud industry has intensified activities to develop new tire-stud designs that retain their benefits for the motorist but are less damaging to road surfaces. This report describes the development of some of these new tire-stud designs and provides a basis for future realization of further improvement.

HISTORY OF TIRE STUDS

Use of metallic cleats in pneumatic tires is not new and can be traced back to the 1890's. They were at that time used to increase the wear resistance of tires and to provide better protection against damage on rough gravel roads. Better roads and improved tires made these cleats unnecessary. However, especially in Scandinavia, a variety of these traction devices are still used for ice races and winter rallies to increase friction on ice- or on snow-covered road surfaces. The effectiveness of these cleats is very limited because, on bare pavements, they are by far less wear resistant than the tread rubber and wear out rapidly.

The first studs with tungsten carbide cores (to achieve a wear performance comparable to tire-tread rubber) appeared in Scandinavia in the late 1950's (Fig. 1).

Fundamental research (36) generated the single-flange tire-stud design (Fig. 2), which has since been adopted by most of the world's tire-stud manufacturers. The only substantial change between the first single-flange design and those in use today has been the use of somewhat softer carbide, which resulted in a slight reduction of the average tire-stud protrusion, as follows:

Year	Protrusion (in.)	Year	Protrusion (in.)
1966	0.087	1969	0.074
1967	0.081	1970	0.068
1968	0.076	1971	0.065

PAVEMENT WEAR TESTS

Preliminary Laboratory Studies

Initial attempts to determine a wear ratio between a tungsten carbide tire-stud pin and a road surface were a failure. The method employed was to press a spring-loaded tire stud against a soft, low-speed grinding wheel (Fig. 3). The results of this test, which was primarily set up to determine differences in wear resistance of various carbide grades, did not correlate at all with actual road test findings.

The second approach was to use a device in which a spring-loaded (30 lb) tire stud slides over a pavement specimen with a velocity of 2.5 in./sec (Fig. 4). After each pass, the specimen is moved sideways to avoid having the stud slide more than once in the same groove. The results of this test gave a good indication of the wear resistance of different carbide grades but did not give a true indication of road wear under actual driving conditions. The specific wear (loss in weight of the pavement specimen, in grams, divided by the loss in weight of the carbide pin, in milligrams), ranged from 250 to 350 depending on the wear resistance of the pavement and the carbide grade used. However, these figures are valid only for driving conditions with 100 percent tire slip (acceleration with spinning wheels, braking with locked wheels, or 100 percent sideslip.)

To duplicate the pavement wear that would be caused by studs in a free rolling tire or a tire with limited slip required that a completely different test arrangement be developed (Fig. 5). A spring-loaded axially oscillating stud hits a slowly rotating pavement specimen with a frequency of 30 cps. The oscillating unit moves sideways across the centerline of the rotating pavement block. Wear of the pavement is not uniform across the test block because the number of impacts per surface area unit and the length of the gliding way between the stud and the specimen are functions of the specimen's radius (Fig. 6). The evaluation of the results had to be made individually for a number of concentric ring sections. Figures 7 and 8 show that the specific pavement wear increases with the force between the stud and pavement and with the sliding length of the stud on the pavement surface. This latter result explains why there is relatively more wear to road sections where slip between tires and pavement surface is more likely to occur. For example, intersections, curves, and tollgate lanes will usually show more wear than straight road sections carrying rolling traffic.

Tests With Road-Wear Simulator

To provide more practical results, a road-wear simulator was built, as shown in Figures 9, 10, and 11. Identical concrete pavement mixes (class A, Pennsylvania Department of Transportation specifications) were used. The minimum curing time was 60 days. The pavement specimen was slowly moved laterally so that uniform pavement wear would occur across the entire surface of the specimen (Fig. 12). The rather short length of the revolving arm of the machine once again resulted in abnormal longitudinal and lateral slip between the tire stud and the pavement surface. However, the results can be related to actual road wear by introduction of a constant correction factor. The following variables were tested.

1. Studs per tire—The number of studs per tire and road wear increase at a linear rate (Fig. 13).
2. Tire-stud protrusion—There is a linear increase in road wear with increasing protrustion (Fig. 14).
3. Tire-stud flange diameter—The diameter of the flange affects the force exerted by the stud on the road surface (Fig. 15). Studs having a small flange offer less resistance and are pushed back into the tire during their contact with the road.
4. Tire construction—Tests were made with radial, bias-belted, and 4-ply bias tires. No differences in road wear could be determined. It can be assumed that studded radial tires cause less road damage at higher speeds than bias ply tires because tires have less squirm on the road and consequently less slip between stud and pavement. However, this effect could not be proved on the road-wear simulator at a speed of only 15 mph.
5. Shape of carbide pin—The sharp edges of the tire studs with flat-tipped pins have a serious cutting effect on the pavement until the tip is worn off to a smooth radius (Fig. 16). This usually happens during the first 500 miles of normal driving, which is equivalent to approximately 50 hours of running time on the road-wear simulator. Figure 17 shows substantial wear differences between a stud with a sharp-edged flat carbide pin and a stud with a new domed pin. After about 50 hours of running time, both pins have the same shape and will have the same pavement wear effect.
6. Weight of studs—No differences in pavement wear could be found in similar studs of different weight. The reason again is the low speed on the simulator; there is negligible variation in the dynamic force of studs with different weight against the pavement at a speed of 15 mph.

Dynamic-Force Measurements

Special force-measuring tire studs (Figs. 18 and 19) made it possible to measure the dynamic axial forces of tire studs against the road surface. These measuring devices, identical in size to regular tire studs, contain 4 strain gauges wired in double bridge network. The protrusion of these measuring studs can be varied by changing the replaceable pins. The use of pins with various heavy metal inserts also allowed tests with different stud weights.

Figures 20 and 21 show a schematic of the test arrangement, description of the test car, and its equipment.

The test car was a 1970 Oldsmobile Cutlass S with the following options: 350 $in.^3$, 310 hp, turbo hydra-matic, extra heavy duty suspension (includes rear sway bar), power disc brakes, power steering, and air conditioning. The dimensions were as follows: front tread width, 59.0 in.; rear tread width, 59.0 in.; wheelbase, 112.0 in.; test weight (with equipment and personnel), 3,940 lb; and weight distribution front to rear, 55 to 45 percent.

Preliminary tests showed that the structure of the pavement surface does not affect the results. On smooth surfaces, however, the forces are more uniform, which makes it easier to evaluate the recordings. Tests on both front and rear wheels also resulted in no significant differences. This allowed us to eliminate most front-wheel tests.

The resolution of our measuring system allowed us to analyze the forces throughout the entire contact between stud and pavement surface. The highest forces occur the

Figure 1. First tire studs with tungsten carbide cores.

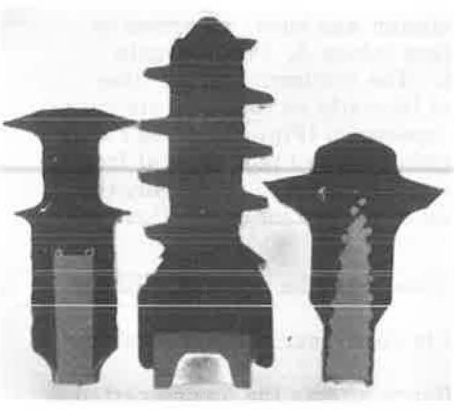


Figure 2. Cross section of single-flange tire stud.

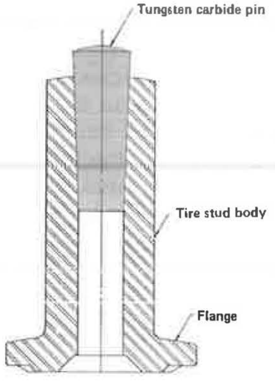


Figure 3. Early attempt to determine wear ratio between stud pin and road surface.

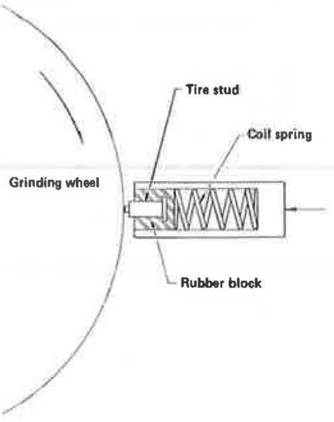


Figure 4. Second attempt to determine wear ratio between stud pin and road surface.

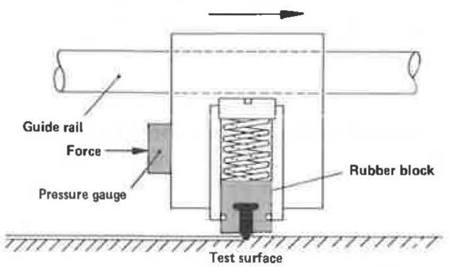


Figure 5. Later test arrangement for duplicating pavement wear.

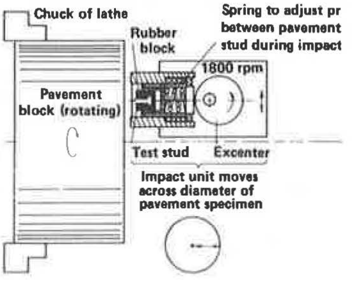


Figure 6. Detail of pavement-wear simulation.

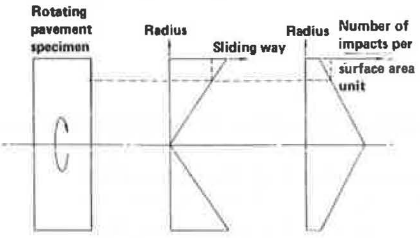


Figure 7. Pavement wear increases with increase of force.

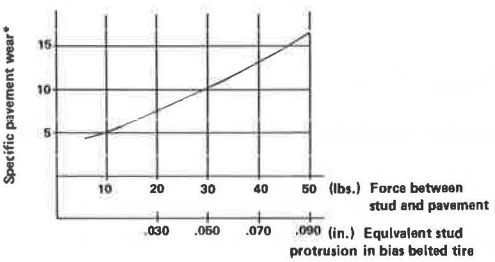
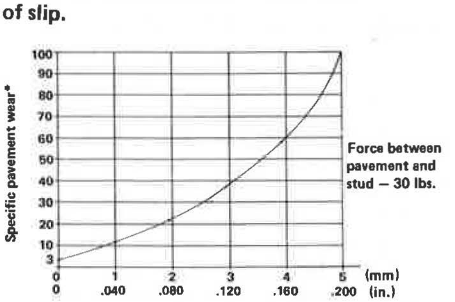


Figure 8. Pavement wear increases with increase of slip.



$$\text{*Specific pavement wear} = \frac{\text{Loss in weight of road specimen (grams)}}{\text{Loss in weight of carbide pin (milligrams)}}$$

Figure 9. Top view diagram of road-wear simulator.

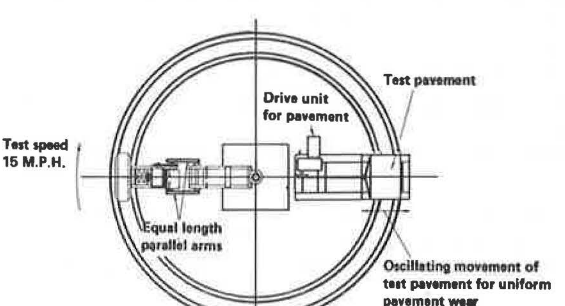


Figure 10. Side view diagram of road-wear simulator.

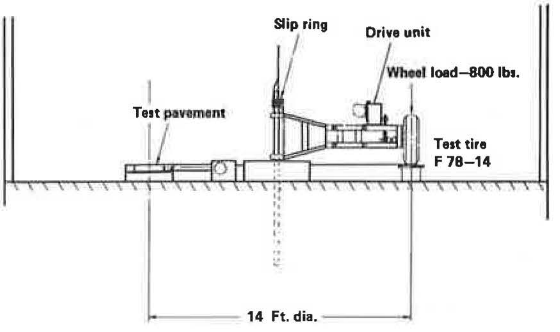


Figure 11. Road-wear simulator.

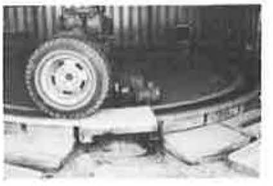


Figure 12. Closeup of pavement section in road-wear simulator.

Figure 13. Effect of number of studs per tire on pavement wear.

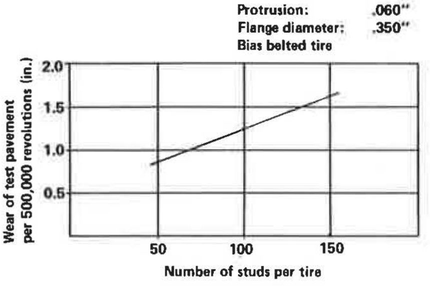


Figure 14. Effect of stud protrusion on pavement wear.

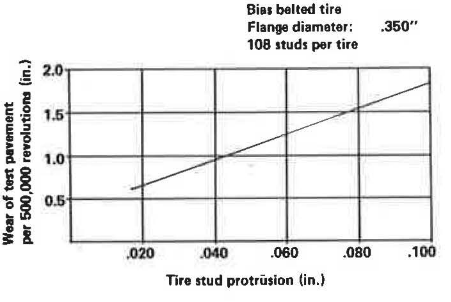


Figure 15. Effect of flange diameter of stud on pavement wear.

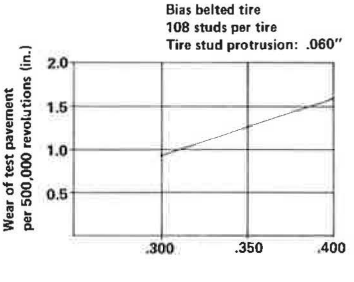


Figure 16. Pavement contact by 2 types of stud pins.

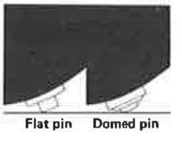


Figure 17. Relative pavement wear by 2 types of stud pins during first 50 hours of use.

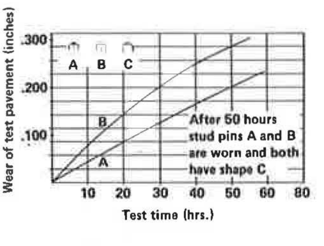


Figure 18. Cross section of special force-measuring tire stud.

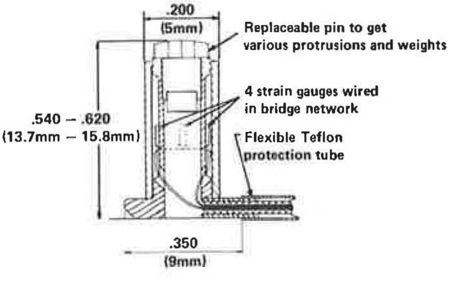
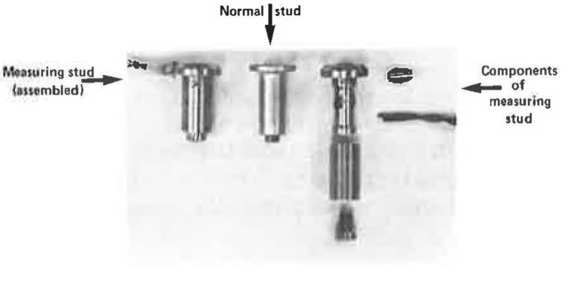


Figure 19. Comparison of special force-measuring stud with standard stud.



first moment the stud hits the road—inertial force required to push the stud back into the tire (Fig. 22). This initial impact is shown in the following figures as "dynamic force."

1. An increase of the force with higher vehicle speeds seems logical due to an increase in the inertial force (Fig. 23).
2. The relation between the dynamic force and the tire-stud protrusion is almost linear (Fig. 24)
3. It is quite obvious that the tire-stud weight becomes a very important influence on the dynamic forces, and it can be assumed that it affects pavement wear at a similar rate (Fig. 25).
4. Tire-inflation pressure and wheel load have no substantial effect on the tire-stud forces. Studs with larger flanges create higher forces (Fig. 26).
5. Thickness of the base rubber is the distance between the stud flange and the cord (Fig. 27). More "undertread," which acts like a rubber spring during the contact between the stud and the road, increases the resiliency and consequently reduces the dynamic forces. We could not find a reduction in force of 50 percent by doubling the undertread thickness (as reported by Scheuba, 37). Figure 28 shows, however, that the dynamic force is decreased by approximately 27 percent as the undertread thickness is doubled from 0.080 to 0.160 in.
6. Bias-belted and radial tires showed no significant difference in the dynamic force.
7. The dynamic force of tire studs with a center cavity and 4 symmetrically oriented pockets (Fig. 29) is, under all tested conditions, 4 percent lower than the forces of identical studs with flat flanges.

NEW TIRE-STUD DEVELOPMENTS

Road-wear test results and dynamic-force measurements show that the following changes in tire-stud or tire designs can reduce road wear: decreased tire-stud protrusion, reduced tire-stud weight, smaller flange diameter, increased undertread thickness, reduced number of studs per tire, increased resiliency of the undertread, and modified flange design. Several of these opportunities for road-wear reduction have been incorporated into the tire-stud designs described in the remainder of this report.

CP Stud

Basic changes are weight 18 percent lighter and flange 5 percent smaller. The new Kengrip controlled protrusion (CP) stud is designed in such a way that the tapered pin will move farther into the jacket as soon as a critical level of dynamic force is reached (Fig. 30). This dynamic force is determined primarily by the tire-stud protrusion and partially by the speed of the vehicle. This means that the studs maintain a certain protrusion level almost independent from the driving conditions and the wear resistance of the carbide pin and the tire.

The protrusion maintained by conventional studs during use is determined by the grade of carbide used for the pin, the wear resistance of the tire tread, and the driving conditions. The carbide grades in most of the tire studs in use today are the result of a great number of road tests. Generally they give uniform tire-stud protrusion for most drivers. Figure 31 shows a stud-tire combination that was developed for an average tire life of 16,000 miles, which is equivalent to a ratio of 0.028-in. tread wear per 1,000 miles. At this rate tire studs and the tire are wearing equally. If a driver has more tire wear because of more severe driving conditions, he may, for example, get a tire lifetime of only 10,000 miles with the same tire and stud combination. Under such conditions, it is probable that the tire will be wearing faster than the studs, which will result in an increase of protrusion. On the other hand, a driver who gets a higher tire mileage will experience a loss of tire-stud protrusion, for the tire studs will wear faster than the tread rubber. The new CP stud design reduces this problem.

The dimensions of the tapered pin and the shape and dimensions of the hole in the body determine the critical minimum force that is necessary to move the pin. This pin movement determines the tire-stud protrusion. The average protrusion with these CP

Figure 20. Test equipment used for dynamic-force measurements.

Figure 21. Equipment layout for force measurements.

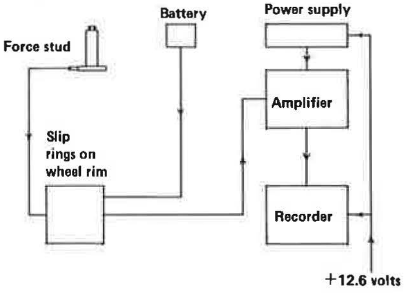


Figure 22. Dynamic force is greatest at moment of impact.

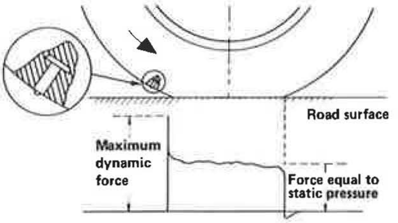


Figure 23. Dynamic force increases with vehicle-speed increase.

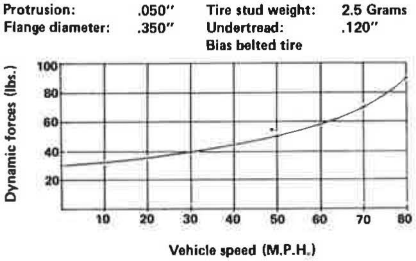


Figure 24. Dynamic force increases with protrusion increase.

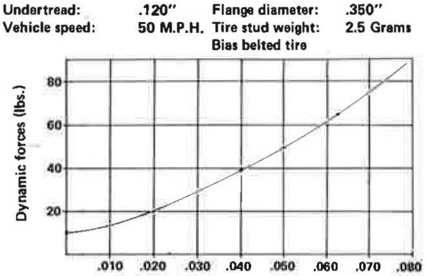


Figure 25. Dynamic force increases with stud-weight increase.

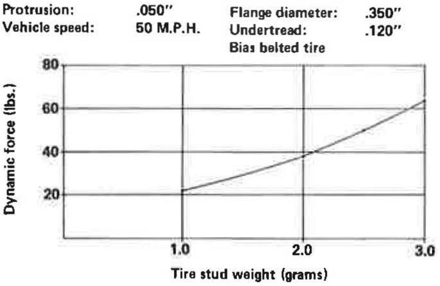


Figure 26. Dynamic force increases with flange-diameter increase.

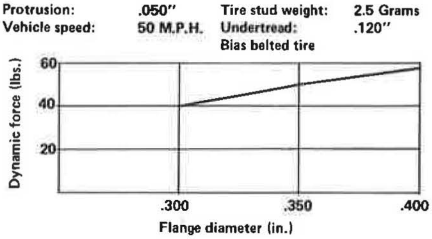
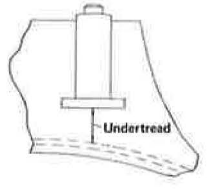


Figure 27. Undertread is distance between stud flange and tire cord.



studs is 0.040 to 0.050 in., approximately 30 percent less than the average tire-stud protrusion on vehicles in the winter season of 1970-1971. Tests show a reduction of 40 to 50 percent in road wear with this new CP stud.

Another advantage of the shortened protrusion is a reduction of the heat created during the impact of the tire stud on the road. Thus, the temperature between the stud and the tread rubber is lower. This in turn eliminates degeneration of the rubber around the stud, which is the main reason for undesired enlargement of the hole in the tire tread (Fig. 32). Manufacturing of this CP stud design is difficult because very close tolerances must be maintained.

CP Stud With Threaded Hole

The pin of this design (Fig. 33) is also able to move into the stud body. The movement is controlled by the force on the road and by the wearing of the body. The pin is basically locked in the body at its larger end by only 2 or 3 turns of the thread. If the stud starts to protrude too far, the end of the body breaks off (Fig. 34). This reduces the holding force, and the pin can move farther into the body. An advantage of this design is that the pin movement depends much less on the accurate dimensions of the body hole and the pin.

CP Stud With Wire Coil in Plastic Body

Figure 35 shows a cross section of the design of a tire-stud body that consists of a coil spring molded in plastic. The carbide pin is held in its position by only the 2 or 3 windings at the end of the coil spring. In case of excessive protrusion, the soft plastic material will be worn away on the pavement surface, and that causes the end of the coil to open up. This, in turn, reduces the holding force between body and pin, and the pin moves farther into the body. These studs have a weight of only 1 gram. Preliminary pavement wear tests show a reduction in road wear of as much as 65 percent compared to conventional steel studs.

FUTURE DEVELOPMENTS

A still newer approach, which could in the future reduce road wear even more is the attachment of a soft spring-like rubber cushion underneath the tire-stud flange (Fig. 36). Preliminary tests indicate that this could reduce the forces between the stud and the pavement surface as much as 40 percent. The forces remaining would still be sufficient to provide a grip on ice even at very low temperatures. This cushion could be made of a material that gets increasingly soft as temperatures go higher and stiffer as temperatures go down. This would increase the forces on ice surfaces when they are needed and would decrease them at higher speeds on bare pavements when the tire stud and the tires get hotter.

Research has been initiated, and results can be expected in the near future.

CHANGES IN TIRE DESIGNS

When tire studs were introduced, most tire manufacturers retained their existing tread designs and changed their molding procedures to simply add holes for tire stud installation. In most cases, there was not enough rubber around the stud to give adequate support. Too much flexibility allowed the stud to move away laterally, which caused irregular stud wear and irregular tire-stud protrusion. Generally, the studs had a tendency to "grow" out of the tire and, thus, increase road wear.

In new winter-tire designs (Fig. 37), the rubber area around the stud holes has been increased to provide sufficient support and eliminate lateral movement. Another tire design change being implemented is the molding of tire-stud holes with a configuration different from any previously made (Fig. 38). The new hole has a cavity at its end to receive the stud flange.

Tests have shown that with the previously used cylindrical hole the initial stud protrusion in new tires depends greatly on the pressure that is applied to the stud gun (Fig. 39). The new hole design eliminates most of the dependency on human skill (Fig. 40),

Figure 28. Dynamic force decreases with undertread increase.

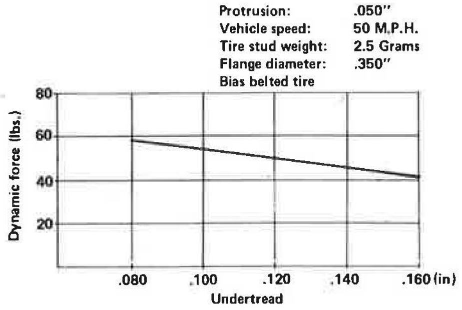


Figure 29. Stud with 4 symmetrically oriented pockets and center cavity (left) and flat flange (right).

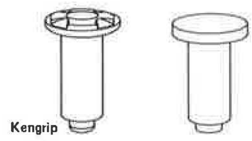


Figure 30. Stud currently used and new CP tire stud.

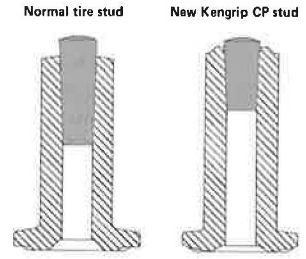


Figure 31. Relation of useful tire life to stud protrusion.

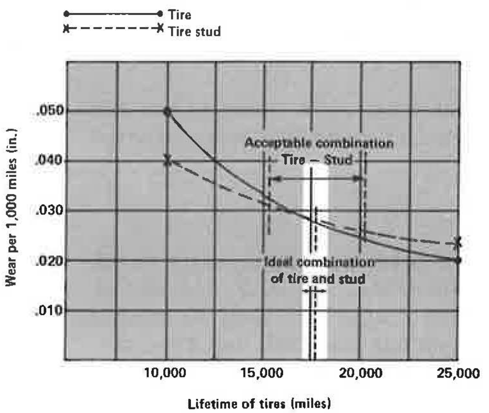


Figure 32. Effect of stud protrusion on heat generation.

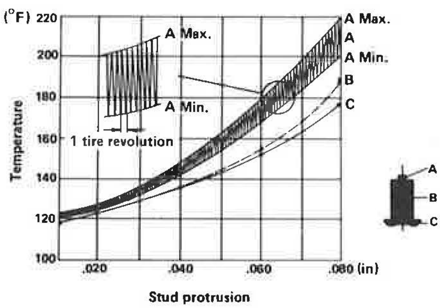


Figure 33. Experimental stud with threaded cavity for pin.

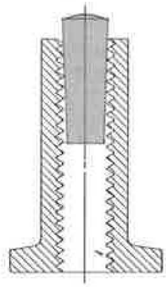


Figure 34. Characteristic wear of experimental stud.

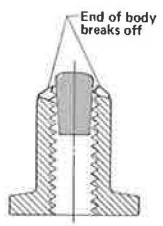


Figure 35. Experimental stud with wire coil embedded in plastic body.

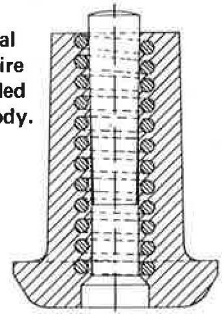


Figure 36. Experimental stud with rubber cushion beneath stud flange.

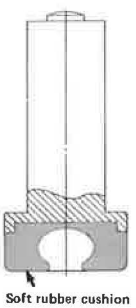


Figure 37. Old and new tread patterns.

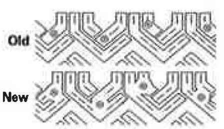


Figure 38. Old and new mold pins.

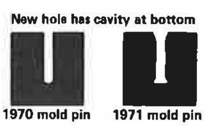
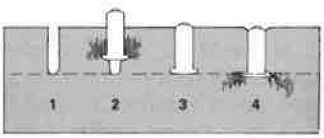
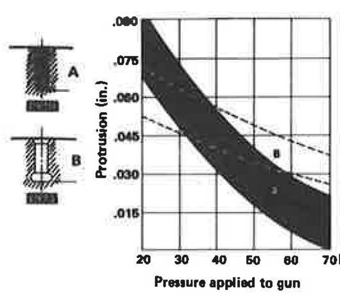


Figure 39. Stud installation.



(1) cylindrical hole (2) too little pressure and too much stud protrusion (3) correct position (4) too much pressure, no stud protrusion, and cracks in surrounding rubber caused by excessive elongation.

Figure 40. Effect of gun pressure.



and the stud will automatically adjust to its correct position during the first 100 miles of driving.

PERFORMANCE OF STUDDED SNOW TIRES

A great number of studies (5, 7, 9, 12, 14, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47) have been made to measure the effect of studded snow tires on ice-covered, snow-covered, and bare pavements. All reports agree that studded tires, as compared to identical unstudded tires, afford dramatic improvement in vehicle control on glare ice. However, reports concerning bare-pavement performance differ substantially. In some cases, the reason for the differences is that the use of nonstandard test equipment or comparisons between snow tires and highway tires or even the use of different brands of snow treads has produced varying results. Atmospheric temperatures, pavement construction, and surface finish are additional factors that can influence test results.

Figure 41 shows a comparison of some of these results. Both an increase and a decrease in the coefficient of friction have been found on asphalt and concrete, both wet and dry. The advantages and disadvantages on asphalt seem to be balanced. However, the presence of studs seems to have some negative effects on both wet and dry concrete surfaces.

We have conducted our own vehicle performance tests and used the test vehicle with the same options and dimensions as that used for the dynamic force measurements except that the test weight with equipment and personnel was 4,260 lb and the weight destribution front-rear was 54-46 percent. The test equipment is shown in Figure 42, and the equipment layout is shown in Figure 43.

The following sections discuss the result of winter tests that were conducted in 1969-1970 and 1970-1971. They conform with the results of earlier tests that were carried out between 1965 and 1969.

Coefficient of Friction on Glare Ice

Figure 44 shows the coefficient of friction evaluated in vehicle stopping tests at different speeds, ice-surface temperatures, and tire combinations. At 30 F, the use of 4 studded tires offers an increase in coefficient of friction of approximately 90 percent. As temperatures decrease, the advantages of studded tires are reduced, but even at -3 F there is still an increase in the coefficient of friction amounting to 25 percent. A test conducted in 1967 projected that all the effectiveness of studded tires would be lost at -10 F. Current testing, however, could not substantiate that proposition.

Effect of Number of Studs and Their Location

Friction increases with the number of studs per tire (Fig. 45). The tire design used for these tests made it possible to vary the number of rows in which the studs were positioned in the tire tread. Any given number of studs will be more effective on ice when they are located in a greater number of rows. This fact was taken into consideration in the design of most modern winter tires that have stud holes located across the tread in 6 or 8 rows.

Effect of Tire-Stud Protrusion

An excess protrusion of studs in a new tire raises the coefficient of friction (Fig. 46). However, the excessive protrusion, more than approximately 0.050 in., will cause excessive heat buildup in the studs. This in turn destroys the surrounding rubber and reduces the support strength of the stud. Then the studs no longer penetrate the ice so effectively. Thus, although excessive protrusion in a new tire will give a higher coefficient of friction, excessive protrusion in a used tire, with corresponding enlargement of the stud holes, will result in a lower coefficient of friction. Properly installed studs with correct protrusion, especially the CP design, will maintain their effectiveness on ice throughout the lifetime of the tire.

Figure 41. Comparison of stud performance tests.

TESTS MADE BY	KIND OF TESTS	RESULTS: ASPHALT, DRY: FRICTION INCREASE WITH STUDS	ASPHALT, DRY: FRICTION DECREASE WITH STUDS	ASPHALT, WET: FRICTION INCREASE WITH STUDS	ASPHALT, WET: FRICTION DECREASE WITH STUDS	CONCRETE, DRY: FRICTION INCREASE WITH STUDS	CONCRETE, DRY: FRICTION DECREASE WITH STUDS	CONCRETE, WET: FRICTION INCREASE WITH STUDS	CONCRETE, WET: FRICTION DECREASE WITH STUDS	REMARKS	REFERENCE
CANADA SAFETY COUNCIL	STOPPING TESTS 50 M.P.H.		- 0 %		- 0 %		-15 %		-19 %		1970 REPORT
ONTARIO PROVINCIAL POLICE	STOPPING TESTS 50 M.P.H.		- 7 %		-22 %						REPORT RR 165 DEPT. OF HIGHWAY ONT.
STATE OF NEW YORK	SKID TEST RESULTS	+ 1 %		+ 3.5%		+ 5 %		+ 3.5%			PHYSICAL RESEARCH REPORT RR 65-3
UNIVERSITY OF STUTTGART	STOPPING TEST 50 M.P.H.		- 0 %	+13 %			- 7 %		-10 %	TIRE-A	DEUTSCHE KRAFTFAHRT FORSCHUNG UND STRASSEN VERKEHRSTECHNIK 1967
			- 1 %	+ 3 %			-20 %		-20 %	TIRE-B	
TENNESSEE HIGHWAY RESEARCH PROGRAM	STOPPING TEST VARIOUS SPEEDS		- 5 %		- 1 %					PAVEMENT-1	CORNELL AERONAUTICAL LABORATORY REPORT NO. 159
		+ 4 %			- 3 %					PAVEMENT-2	
	SKID TRAILER TESTS	+ 2.5%		+ 1.6%						PAVEMENT-1	
		+ 2.4%		+ 1 %					- 2.6%	PAVEMENT-2	
STATE OF ILLINOIS	STOPPING TESTS 50 M.P.H.	+ 1.7%		+12 %		+ 5 %		+ 1.3%		NEW TIRES	RESEARCH & DEVELOPMENT REPORT NO. 13
		+ 1.7%		+ 3 %			- 8 %		- 3 %	OLD TIRES	
ROYAL CANADIAN AIR FORCE	STOPPING TESTS 40 M.P.H.		- 8 %				- 6 %			LIGHT TRUCK	

Figure 42. Test equipment used for stopping and acceleration tests.

Figure 43. Equipment layout for stopping distance and acceleration measurements.

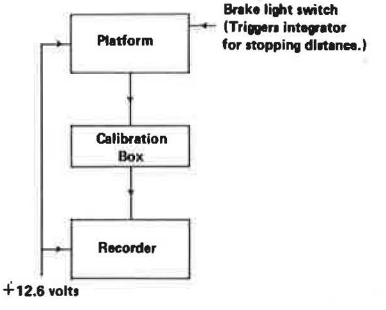


Figure 44. Effect of studded tires on coefficient of friction.

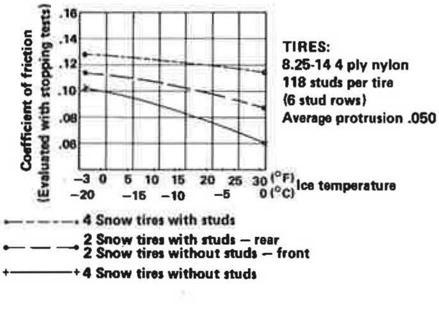


Figure 45. Effect of number of studs on coefficient of friction.

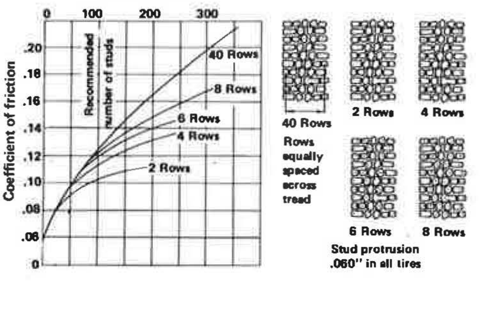


Figure 46. Effect of stud protrusion on coefficient of friction.

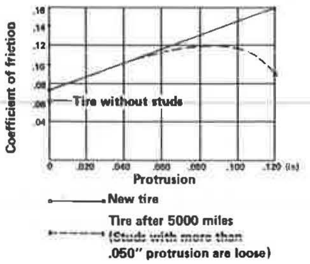


Figure 47. Effect of pin diameter on coefficient of friction.

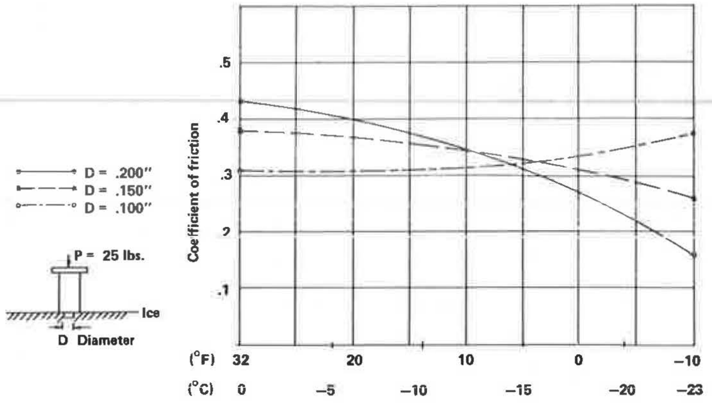


Figure 48. Stopping distances.

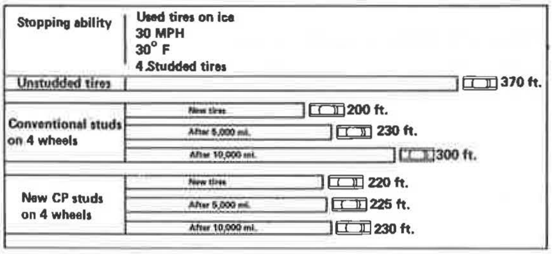


Figure 49. Climbing traction.

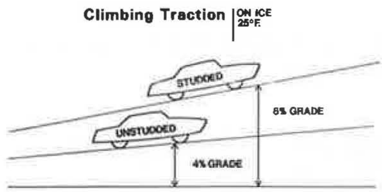


Figure 50. Starting traction.

Figure 51. Cornering ability.

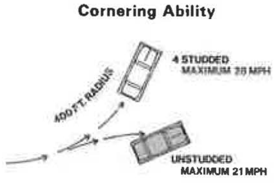
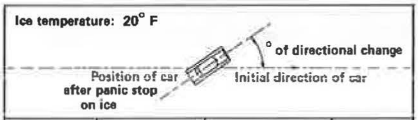


Figure 52. Directional stability.



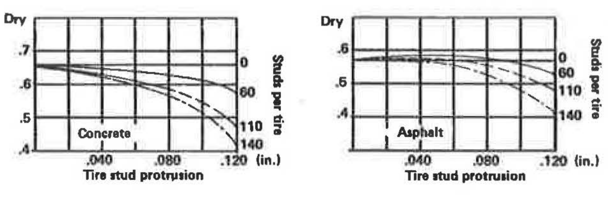
Initial speed of car (MPH)	4 Snow tires (without studs)	2 Snow tires front 2 Studded snow tires rear	4 Studded snow tires
	* Average	* Average	* Average
20	22°	14°	5°
40	90°	26°	12°
60	114°	36°	28°

* 20 Panic stops

Table 1. Percentage increase or decrease of friction compared with tire without studs.

Road Surface	Conventional Studs	CP Studs
Glare ice (30 F)	+85	+70
Packed snow	+11	+8
Loose snow	0	0
Dry concrete	-7.6	-4.5
Wet concrete	-8.8	-5.2
Dry asphalt	0	0
Wet asphalt	+1.9	0

Figure 53. Effect of protrusion and number of studs on coefficient of friction.



Effect of Carbide-Pin Diameter

Tests with 3 different pin diameters show that large pins lose some of their effectiveness at lower temperatures while smaller pins become more efficient (Fig. 47). This is due to their higher force per surface unit. This was taken into account with the CP stud design, which has a pin diameter of approximately 0.100 in.

Stopping Distances With Conventional and CP Studs

Figure 48 shows comparative stopping distances for a vehicle equipped with tires without studs, with conventional studs, and with CP studs. CP studs lose little of their effectiveness after 5,000 and even 10,000 miles of normal use.

Starting Traction, Cornering Ability, and Directional Stability

Figures 49, 50, 51, and 52 show comparisons in starting traction, cornering performance, and directional stability between vehicles with and without studded tires (CP studs).

Coefficient of Friction on Dry and Wet Asphalt and Concrete Surfaces

Test results with various tire and stud combinations are given in Table 1. The loss of friction on dry and wet concrete is less with CP studs than with conventional studs. The reason is the reduced force between CP studs and the pavement, which is caused by the shorter protrusion. Figure 53 shows the effect that protrusion and the number of studs per tire have onthe coefficient of friction, on dry concrete and asphalt pavements.

CONCLUSIONS

It may be impossible to eliminate all pavement wear due to the use of studded tires. However, new tire-stud designs, in combination with improved pavement compositions, can substantially reduce the problem. Indications are that the reduction in road wear thus achieved would be such that resurfacing would not be required any more frequently than normal.

Comparison testing of studded and unstudded tires indicates that studded tires do cause a slight loss of friction on dry and wet concrete pavements. The difference is relatively small when compared to other stopping distance factors such as vehicle weight, speed, and particularly the added distance required for snow-tread tires compared to regular treads. What is more significant is the substantial improvement in vehicle control on icy and snow-covered roads, as established by numerous tests by independent agencies.

Whether the use of studded tires contributes more to motoring safety or convenience is really an academic question. Traffic at horse-and-buggy speeds would surely be safer than traffic at the present legal speeds. But we do not design roads today for horse-and-buggy traffic. Today's highway system has been engineered and built to permit motorists to go where they want to go, with speed, convenience, and safety. Just as windshield wipers, 4-wheel brakes, and headlights serve that purpose, so do studded tires. We believe that a proper sense of values for safety and mobility, as well as convenience, will permit—indeed encourage—motorists to use studded tires for winter driving.

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