Effects of Variable Tire Pressure on Tire Life

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Results were obtained from tests to determine the effects of variable tire pressure on hauling-vehicle tires. Tests address two major categories—tire wear rates and tire carcass life. Results indicate that the larger ground contact area of reduced tire pressure operation, in an off-highway condition, is not detrimental to tire wear, and may be beneficial to tire wear on rough roads where energy is wasted because of a vehicle's bounce or hop. Testing performed to date indicates no detrimental effects on tire carcass life, but it is deemed too early to make conclusive statements on the basis of the tests presented.

Since 1983, the U.S. Department of Agriculture Forest Service has been studying central tire inflation (CTI) as a means of reducing road costs. CTI is a system that enables the driver of a vehicle to control tire pressure from inside the cab while in motion. By matching the tire pressure to road, speed, and load conditions, less damage occurs to existing roads, and less surfacing material is required to support a particular volume of traffic. Testing indicates that significant benefits to low-volume roads can be realized by the use of CTI. Of major interest to the Forest Service is log-hauling vehicles and their impacts on roads. Consequently, most CTI efforts have been directed to studying the effects of reduced tire pressure operation with logging trucks.

One of the primary questions that surfaced early in this program was, "What effects will the reduced tire pressure have on tire performance?" It was clear that unless tires could perform satisfactorily, CTI would have no practical use in reducing costs associated with road construction and road maintenance. Additionally, tire manufacturers have concerns about warrantees on their tires being operated in reduced pressure service. The economics of reduced road costs as a result of using CTI is not addressed, but the effects of CTI on tire wear and the testing that has been performed to validate reduced pressure operation are discussed.

BACKGROUND

There are two major types of tires available for today's vehicles. These are bias-ply and radial tires. Because of the flexible sidewall design, only radial tires should be used for CTI applications.

Traditionally, the load-carrying capacity of all tires has been related to the enclosed air volume and pressure maintained in the tire carcass. In reality, the load-carrying capacity of radial tires is largely related to the tires' structural ability to support the loads through a system of tensile cords that extend from the bead of the tire (near the rim) to the *upper* outside portion of the tire. The current CTI test program addresses the load-carrying capacity of reduced-pressure tires running at restricted speeds.

To understand the principles of operation at reduced tire pressure, it is necessary to understand the concept of tire deflection. Tire deflection is defined as the change in section height from the freestanding height to the loaded height. The percent deflection is the ratio of that change to the freestanding section height times 100 (Figure 1).

Because the goal of a CTI system is to match tire pressure to road, speed, and load conditions, different pressure settings are needed as these conditions change. Typical systems installed today for standard on-highway logging trucks operate at three different pressure settings, on-highway, off-highway loaded, and off-highway empty. Forest Service research conducted by the Southern Forest Experiment Station located in Alabama (*1*), indicated that significant reductions in off-highway road damage occurred as tire deflection approached 20 percent. There was only a minor decrease in road damage as the deflection was increased to 30 percent. Because of this, the goal for off-highway, low-speed operation is to approach a 20 percent tire deflection and avoid the unknown effects of heat build-up with the greater deflection. This 20 percent tire deflection spreads the load of the vehicle over a larger tire footprint. For typical U.S. logging truck tires, this increase is about 60 percent greater in length. Higher-speed highway operation typically averages around 10 percent deflection.

With a goal of achieving a 20 percent tire deflection, tire pressures on different vehicles can vary widely because of a number of factors. These factors include the vehicle's load, axle distribution, and number of tires per axle. For a typical western U.S. logging truck carrying highway-legal loads, tire pressures for highway conditions would be 100 psi in the steers, drives, and trail tires. For an off-highway loaded condition, there would be about 90 psi in the steers and 54 psi in the drives and trailer tires. For an off-highway empty condition, about 80 psi in the steers and 25 psi in the drives and trailer tires would be expected. These settings would be for off-highway operation at speeds under 35 mph. Higher off-highway speeds would require slightly higher pressures to avoid the effects of heat build-up, and have to be set by the individual tire companies. Obviously, there is no CTI restriction on highway speeds.

The U.S. Tire and Rim Association sets tire pressure limits for load and speed for all tire manufacturers conducting busi-

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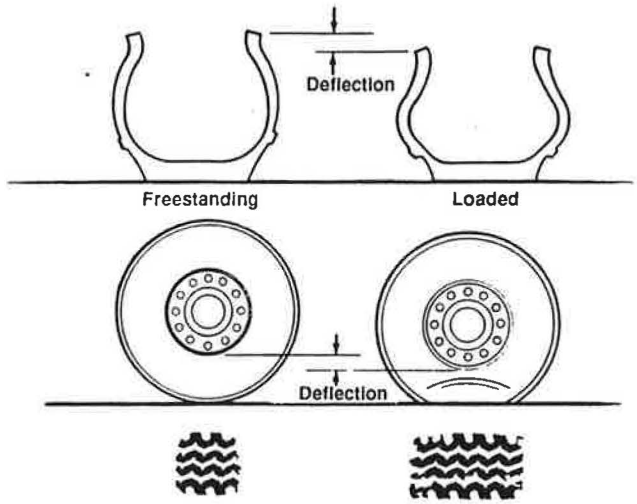


FIGURE 1 Tire deflection.

FIGURE 2 Photograph of a test truck.

ness in the United States. Individual manufacturers can provide additional pressure reductions in accordance with their own criteria, but only by permission of the manufacturer on a case-by-case basis. The Forest Service has obtained interim standards for reduced pressure operation from the U.S. Tire and Rim Association.

TESTING GOALS

The Forest Service has been working with various tire companies, the industry's Tire and Rim Association, and independent testing contractors to determine what effect reductions in tire pressure might have on tire performance. Testing of reduced pressure effects on tires covers two general categories:

1. Tire Tread Wear. These studies examine the effects of reduced tire pressure on rate of tread loss.
2. Tire Carcass Life. These studies examine the effects of reduced tire pressure on the structural performance of the tire. Because multiple retreading of tires is commonplace in the timber industry, the ability to retread a tire several times is being studied under this category.

The following sections cover specific testing procedures and results.

NEVADA AUTOMOTIVE TEST CENTER STRUCTURED TEST

Background

In May 1987, a structured test was conducted by the Nevada Automotive Test Center (NATC) for the Forest Service (*2*). Two identical 18-wheel log trucks were operated on parallel lanes over a closed-loop test course constructed to AASHTO specifications. One truck operated with standard highway tire pressure, the other with reduced tire pressure (Figure 2).

The test course consisted of 12 different roadway sections. These sections included a double penetration chip seal, asphalt concrete, an aggregate section with man-made potholes, and a severe rock course. The severe rock course consisted of implanted rocks, 4 to 6 in. in height with 2.25 in. of contact area. Each pass of the test vehicles over this section resulted in about 35 contacts being made with each rock on a particular tire. There were 520 passes made over the severe rock course, which equates to about 18,200 rock impacts per tire.

Testing Performed

The following tire tests were conducted:

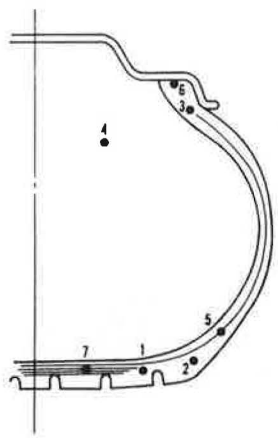
1. Tread wear measurements after 8,833 mi over the test course, which included operation over the severe rock section.
2. Durability determinations of all 36 tires involved in the test. This included both visual observations and X-ray examination of the tire carcass.
3. Tire thermal profile measurements. These were performed using six tires outfitted with thermocouples (Figure 3).
4. Tire bead unseating determinations. Because of the lower pressures, a concern was raised about the tires losing contact with the rims. Visual observations were made during the test to see if this was a problem.

Results

Tread wear results are shown in Table 1. These results are expressed in miles per 32nd of an inch of rubber (mi/32).

The radial tires operated over the closed-loop circuit at reduced pressures experienced approximately 15 percent less tire tread wear than the tires operated at the standard highway pressure.

Tire tread durability results are shown in Table 2. All 36 radial tires applied to the two log trucks at the beginning of the test completed the 8,900 scheduled miles without failure



Thermocouples

Location	Description
No.1	Belt Edge
No.2	Shoulder
No.3	Bead
No.4	Air Cavity
No.5	Carcass Ply
No.6	Bead Bundles
No.7	Belt Plies

FIGURE 3 Locations of thermocouples for NATC project.

or air loss. On the closed-loop course, the high-pressure tires experienced approximately three times as many tread rib cuts, including five cut penetrations to the protector ply, as compared to the lower-pressure tires, which experienced no penetrations to the protector ply. Several of the high-pressure tires would have failed from the number of rocks jammed between the duals if the rocks had not been removed quickly. No rock jamming was experienced by the low-pressure duals.

Tire bead temperature results are depicted in Figure 4. Excessive tire temperatures were not a factor influencing tire durability in this controlled program because average test speeds were below 30 mph when the tires were deflated and thermal profiles showed no excessive heat build up at 20 percent deflection at speeds up to 40 mph.

Bead stability for the higher tire deflection (20 to 22 percent) at speeds used in this test were acceptable. No bead seating problems were encountered at 25 psi.

Tire Manufacturer Testing

Both the Goodyear and Michelin Companies provided tires for this test. Both corporation's representatives examined the test tires on completion of the test. The examinations by both firms noted no significant differences between tires inflated at the standard highway pressure and those operated at reduced pressure. In a letter forwarded to the Forest Service, Michelin reported the following:

> The information obtained from the NATC proof of concept test does not indicate a loss of performance in the areas of tread aggression, wear, or crown injury as a result of running at the specified reduced pressures and speeds. The tests, having been of short duration, don't provide an indication of long-term carcass endurance. We do feel that the reduced pressure will have an ultimate effect on bead cracking, radial splits, etc. This tendency will be reduced in the logging application where carcasses are normally retired from service for other reasons.

Goodyear stated, "Examination of the 18 tires revealed no abnormalities after completion of the 8,900-mi NATC test."

Goodyear had similar concerns regarding long-term effects of reduced pressure operation and decided to initiate a rigorous field evaluation.

GOODYEAR FIELD EVALUATION TEST

Background

The Goodyear Tire and Rubber Company initiated an extensive tire evaluation of standard highway pressure tires (99 psi

TABLE 1 COMPARISON OF TREAD WEAR BETWEEN STANDARD- AND REDUCED-PRESSURE TIRES OPERATING OVER THE NATC TEST COURSE

	Standard Highway Pressure Vehicle (8-12% Deflection)		*Reduced Pressure Vehicle (20-22% Deflection)*	
Tire Position	Avg. % Worn	Miles/32	Avg. % Worn	Miles/32
#1 Axle, Steer Tread Wear, 2 Tires	44.0	1081	43.8	1085
#2 Axle, Drive Tread Wear, 4 Tires	27.9	1736	24.1	2016
#3 Axle, Drive Tread Wear, 4 Tires	54.2	883	45.9	1052
#4 Axle, Trailer Tread Wear, 4 Tires	17.1	2367	14.6	2815
#5 Axle, Trailer Tread Wear, 4 Tires	31.8	1291	28.6	1440

TABLE 2 COMPARISON OF TIRE DAMAGE BETWEEN TEST VEHICLES OPERATED AT NATC IN TERMS OF NUMBERS OF INJURIES ON COMPLETION OF TEST

Tire Damage Noted	*Standard Highway Pressure Vehicle* 8-12% Deflection	*Reduced Pressure Vehicle* 20-22% Deflection
Undercut Flex Cracks	504	303
Rib Cuts	147	49
Rib Cuts to Belt	5	0
Tread Cut Chunkouts	171	35

hot) versus tires run on CTI equipped logging trucks during January 1989. Two fleets, FJM Trucking of Roseburg, Oregon, and Foglio Trucking of Florence, Oregon, were chosen as the test fleets for control versus CTI tires.

Tread depth data were gathered using an electronic data collection system. Each tire involved in this field evaluation was uniquely numbered and its position known at all times.

There were some concerns raised that the standard highway pressure tires would benefit from the pneumatic rolling effect of the reduced pressure tires. In other words, the highway pressure tires would realize some of the benefits of the CTI tires by having a smoother road to traverse. It was decided to note this fact, but to proceed with the test anyway since there was no feasible way to gather actual field data without pairing the CTI and non-CTI vehicles to operate over the same road.

FJM Trucking

At FJM Trucking of Roseburg, Oregon, the test tires ran on Kenworth log trucks, which had 400-hp engines. Two separate tests were run at FJM. The first test ran from January through April 1989. One CTI truck ran directly against one truck without CTI (the control vehicle). The two trucks ran side by side, always going to the same timber landings.

A typical trip for FJM would involve spending up to 2 hr on an Interstate highway at 55 mph, then 20 to 40 min off the highway at speeds under 35 mph to the landing site. On the average, three round trips per day were made by FJM. Less than 10 percent of the tire life was spent off the paved highway.

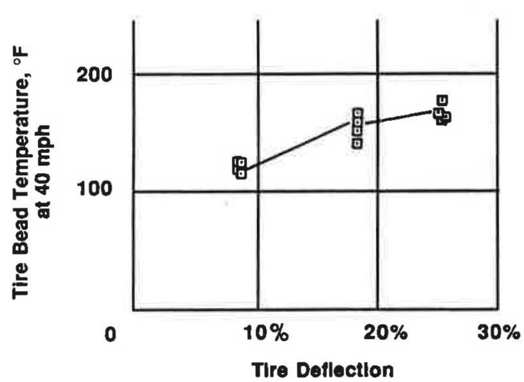


FIGURE 4 Bead temperatures for 11R24.5 drive tires.

In the first test at FJM, the control tires were set at 99 psi hot for all wheel positions (steer, drive, trailer). The CTI tire pressure varied depending on load and speed. When the vehicle was operating on the highway at speeds over 35 mph and fully loaded, the tire pressures were set to the same level as the control vehicle. When the CTI truck ran at speeds under 35 mph and fully loaded, the steer tires were adjusted to a reduced pressure of 90 psi, and the drive and trailer tires were adjusted to a reduced pressure of 57 psi.

When the CTI truck ran at speeds under 35 mph with an empty load, the steer tires were adjusted to a reduced pressure of 90 psi (same as fully loaded), and the drive tires were adjusted to a pressure of 28 psi. Trailer tire pressure was not a factor when the vehicle contained an empty load because trailers ride to the landing "piggyback."

Figure 5 shows the steer tire test results when the CTI tires were reduced to a pressure of 90 psi off-highway. The control tires averaged 26,060 mi versus 23,190 mi for the CTI tires. Miles/32nd of an inch was 1,446 versus 1,262, respectively. Statistically, at a 95 percent confidence level, there was no difference in treadwear.

Figure 6 shows the results of the second test at FJM, which evaluated only steer tires. Tire pressure was reduced down to 70 psi when off the highway and at speeds under 35 mph. Tires ran from April through August 1989. Treadwear increased approximately 15 percent from the first test for both control

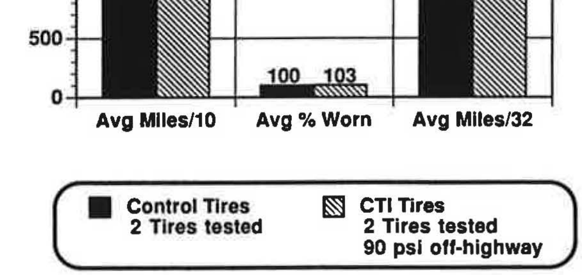


FIGURE 5 Load per tire on steer tires with CTI tires at 90 psi, off-highway (FJM Trucking Co.).

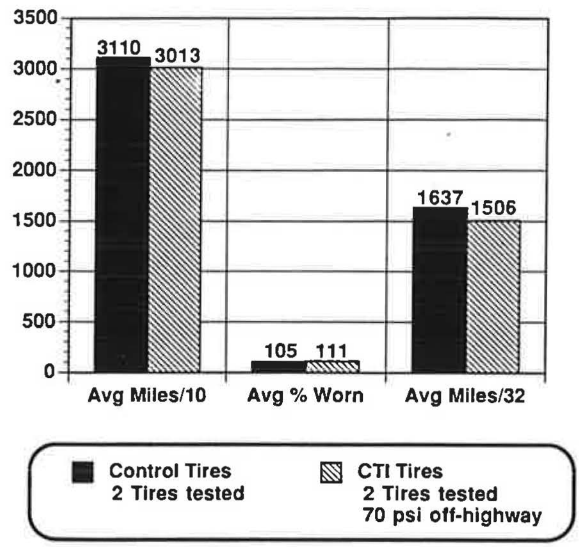


FIGURE 6 Load per tire on steer tires with CTI tires at 70 psi, off-highway (FJM Trucking Co.).

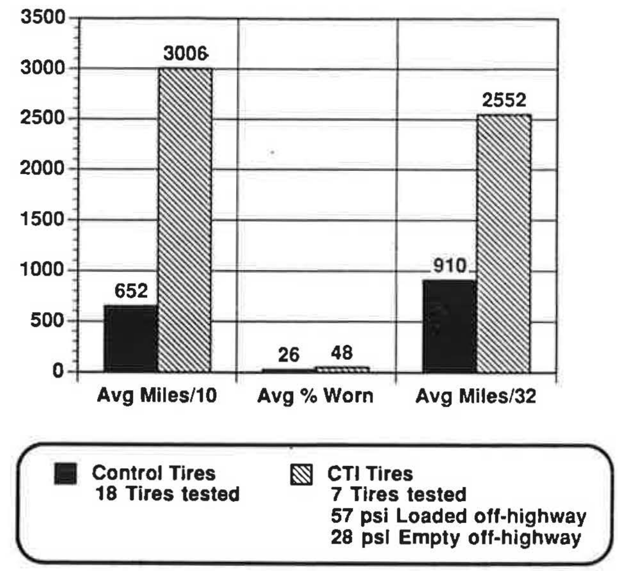


FIGURE 8 Load per tire on drive tires for Retread 1 with CTI tires at 57 psi, loaded, off-highway, and 28 psi, empty, off-highway (FJM Trucking Co.).

and CTI tires. This was primarily because of two factors, a change in landing site and a seasonal effect. The control tires averaged 1,637 versus 1506 mi/32nd of an inch for the CTI tires. Once again, at a 95 percent confidence level, there was no difference in treadwear at this reduced pressure.

Figure 7 shows the drive tire data. Control tires averaged 70,930 mi to removal versus 67,980 mi for the CTI tires. Tread wear was almost identical at 2,622 versus 2,641 mi/32nd of an inch, respectively.

After tires have finished running through their original life, tires are holographed, inspected, and then retreaded. Steer and drive tires are both capped with a G188 drive tire design and run on the drive position. Figure 8 shows the latest data of Retread 1 on the drive position. It is too early to draw any conclusions as to treadwear rating because mileages are still early and not all tires were inspected. Therefore, all tires were retreadable, and holographic analysis revealed equivalent residual durability after running through its original tire life.

Figure 9 shows the trailer tire data. These tires are just beginning to come out of service before getting their first retreading. Tread wear was 2,319 mi/32nd of an inch for the control vehicle versus 2,920 mi/32nd of an inch for the CTI vehicle.

Foglio Trucking

At Foglio Trucking of Florence, Oregon, two control trucks were run versus two trucks with CTI. A typical trip for a

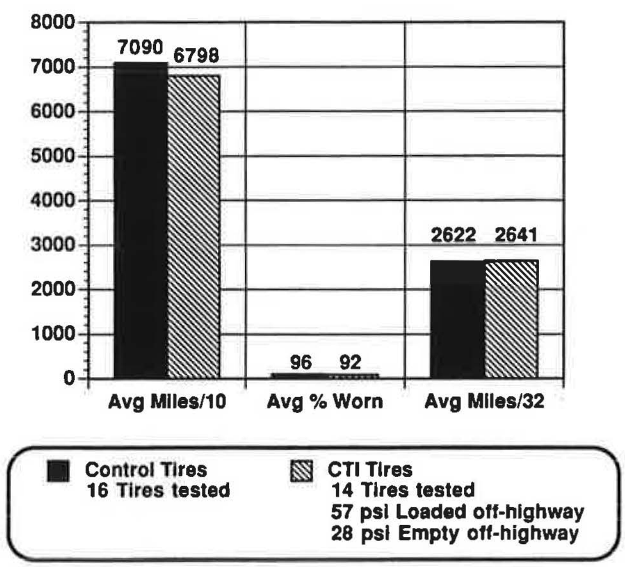


FIGURE 7 Load per tire on drive tires with CTI tires at 57 psi, loaded, off-highway, and 28 psi, empty, off-highway (FJM Trucking Co.).

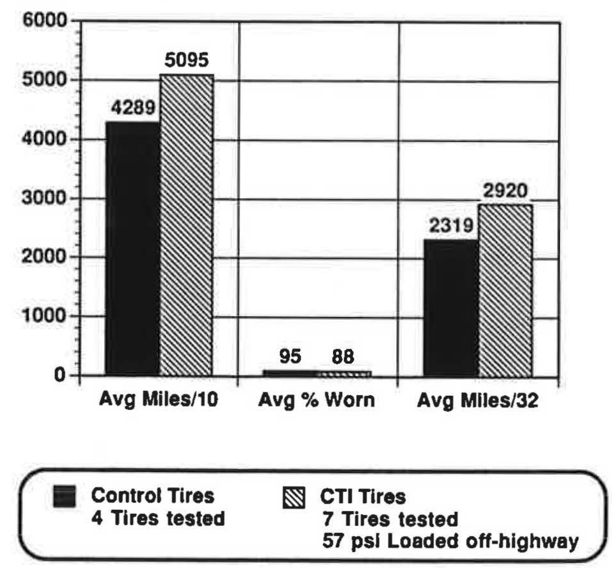


FIGURE 9 Load per tire on trailer tires with CTI tires at 57 psi, loaded, off-highway (FJM Trucking Co.).

Foglio truck would involve 20 to 30 min on the paved highway at 55 mph followed by 20 to 40 min off the highway at speeds under 35 mph. Over 35 percent of the tire life is spent off the highway. Control trucks operated on the same roads as the CTI trucks.

Steer, drive, and trail tires on the control trucks were set at 99 psi hot. CTI trucks, when on the highway at speeds over 35 mph, also operated at 99 psi hot. When the CTI trucks were off the highway at speeds under 35 mph, steer tires were set at 82 psi, drive tires at 57 psi hot when loaded, and 28 psi hot when empty. Trailer tires on the CTI trucks were set at 57 psi hot when off the highway and under 35 mph.

Tires were mounted January 1988 and ran during most of the year. Figure 10 shows that the steer tires averaged 34,670 mi to removal on the control trucks versus 33,470 mi on the CTI vehicles. Tread wear in mi/32nd of an inch was 1,860 on the control versus 1,700 for CTI. Statistically, at 95 percent confidence level, there was no significant difference in treadwear.

These tires were retreaded and are now running as drive tires (G188 design). Data are very early and are shown in the next graph.

Figure 11 shows drive tire data. The control tires averaged 1,955 mi/32nd of an inch versus 1,725 mi/32nd of an inch for CTI tires. Once again, statistically at 95 percent confidence level, there was no difference in treadwear.

Figure 12 shows the first retreading of the drive tires. The procedure for inspection and holographing was identical to the FJM operation. All tires were retreadable with no major defects noted.

Trailer data are shown in Figure 13. At 50 percent worn, control tires are averaging 4,316 mi/32nd of an inch versus 4,431 mi/32nd of an inch for tires run on CTI vehicles. At 95 percent confidence level, there was no difference in treadwear.

Retreadability

Tire retreadability is an important factor in the CTI equation. In logging service, tires generally are recapped three or four times. As part of the Goodyear field evaluation, all tires that are being followed will be retreaded as many times as possible. It is important to determine what, if any, effect CTI may have on running tires with reduced pressure and increased deflection.

All tires at both Foglio Trucking and FJM Trucking were retreadable after running their original life. Holograph data revealed no difference so far between control and CTI tires. It will take up to 3 years before multiple retreadability studies will be completed.

Field Evaluation Conclusions

The Goodyear Tire and Rubber Company has the following conclusions from its field evaluation:

- Original tread water was equivalent for the tires which operated with or without CTI;
- At the end of original tire life, CTI tires were acceptable for retreading;
- Tread wear varies significantly from location to location, i.e., low, moderate, and fast tire wear rates; and
- Because of many uncontrolled test variables, only tires run at the same time, at the same location, using the same roads, can be directly compared.

SUMMARY AND CONCLUSIONS

Currently, it appears that there are no detrimental effects of reduced tire pressure operation on tread wear provided speeds are reduced accordingly. The NATC study indicated a decrease in tire wear for tires operating under reduced tire pressure, whereas Goodyear's study indicated that it was too close to make any conclusive statement one way or the other. The severity of the NATC test course, which was constructed to

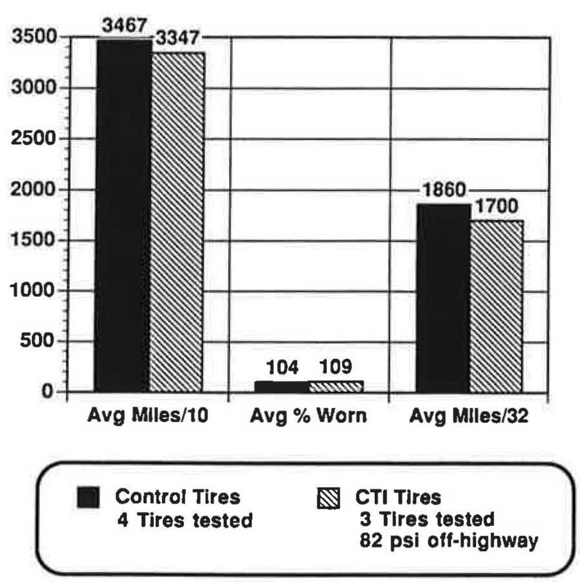


FIGURE 10 Load per tire on steer tires with CTI tires at 82 psi, off-highway (Foglio Trucking Co.).

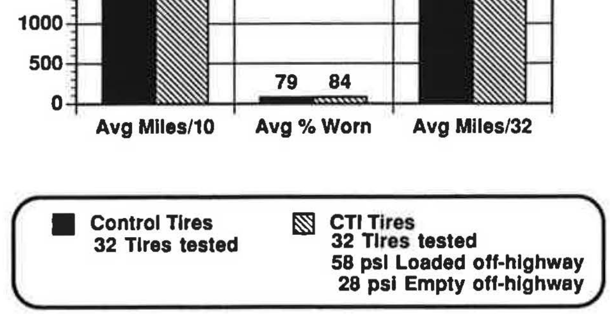


FIGURE 11 Load per tire on drive tires with CTI tires at 58 psi, loaded, off-highway, and 28 psi, empty, off-highway (Foglio Trucking Co.).

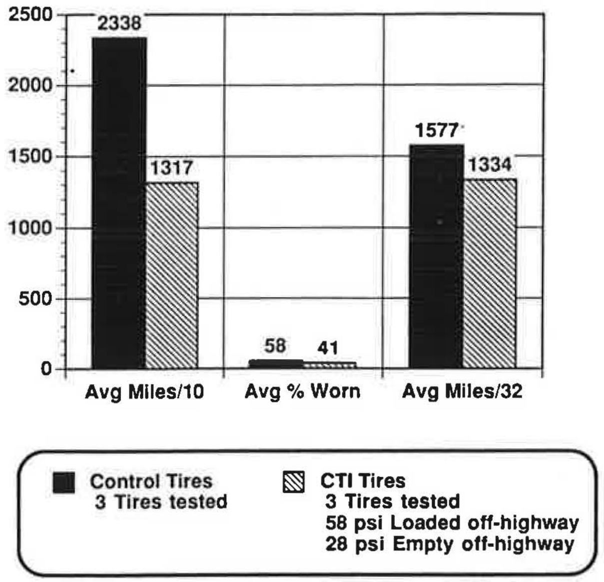


FIGURE 12 Load per tire on drive tires for Retread 1 with CTI tires at 58 psi, loaded, off-highway, and 28 psi, empty, off-highway (Foglio Trucking Co.).

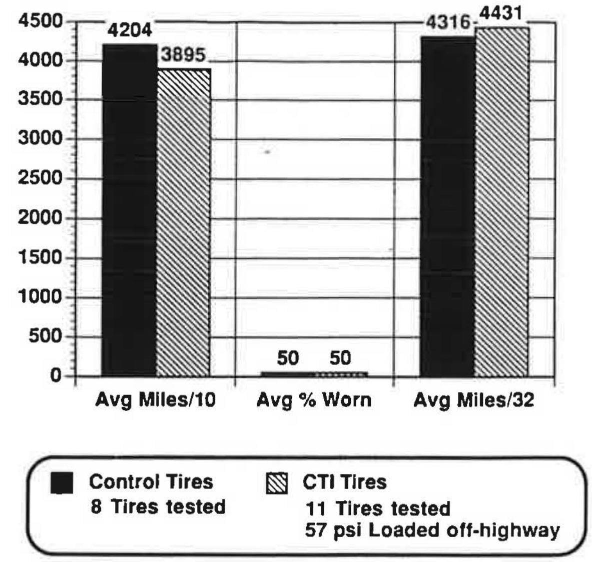


FIGURE 13 Load per tire for trailer tires with CTI tires at 57 psi, loaded, off-highway (Foglio Trucking Co.).

simulate accelerated wear on vehicles and tires, contrasted with less severe field conditions. This difference may account for the variation in results.

The actual amount of tread wear one might obtain is dependent on many factors. Certainly the abrasive quality and particle size of rock aggregate used as surfacing material heavily influence tire wear. Operation at reduced tire pressure would probably exhibit slightly less tread wear over severely washboarded aggregate roads, or roads with numerous potholes. This is because of the softer ride of the reduced-pressure tires, which results in less energy being used to damage the road and tires. Conversely, a smooth surface might cause an increase in tread wear if the tire pressure was reduced beyond the optimum point for efficient traction. The goal of a properly installed CTI system is to match the correct tire pressure to the vehicle's load, speed, and road condition. In any case, it appears that there are no significant detrimental effects on tread wear from operating under reduced tire pressure.

Conclusive results for reduced-pressure tire carcass life have not been determined. While current tests indicate no detrimental effects, it is too early to make predictions as to the outcome.

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