

EFFECT OF TIRE CONSTRUCTION VARIABLES ON PASSENGER TIRE WET TRACTION

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A designed experiment consisting of the three basic tire constructions (diagonal, bias belted, and radial) with three typical tread designs on each tire construction, is utilized to determine the effect of tire construction on wet traction. Significantly, the radial construction itself does not show an inherent advantage for straight ahead wet traction. This fact is better understood as the interaction between the tire footprint and the road surface is explained. Investigation within the radial construction framework shows variables such as stabilizer ply material and ply angle to have little influence on straight ahead wet traction. Only when the radial construction is coupled with a radial type tread design is the full potential realized. The superiority of this combination is even more evident when wet cornering and treadwear evaluations are considered.

The data for the major portion of this experiment were gathered from a matrix of nine tires. Production tires with diagonal, belted and radial constructions were prepared by buffing off the original treads and retreading the carcasses with a common tread compound. Three typical tread designs (diagonal type, belted type and radial type) were then handcut on each of the three constructions. Symbols for the resultant tire combinations are explained in Table 1.

The tread designs, shown in Figure 1, were chosen as being typical of many tread designs used over the years on one particular family of carcass constructions. Siping was not introduced into any of the designs since the attributes of siping for wet traction are well known (1); and the intent of this experiment was to concentrate on construction variables and not delve into intricate design differences.

Braking Traction

Carcass Construction vs. Surface

Present day passenger car tires play a major role in determining vehicle performance, especially in the areas of cornering traction and stopping ability. The stopping ability of any particular vehicle becomes particularly important under adverse driving conditions. Wet pavement conditions are common in most geographical locations and skidding becomes involved in a large percentage of accidents that occur on a wet roadway (2).

As the road surface characteristics can vary greatly (2) during almost any excursion, a tire that is relatively unaffected by changes in surface conditions would be helpful in maintaining vehicle control. In particular, we sought a carcass construction that would offer constant road holding characteristics over a wide range of surface conditions. The matrix of 9 tires was evaluated on a wet traction skid trailer per ASTM std. test method E274-70 on two distinctly different surfaces to find such a construction. The first surface was a relatively smooth concrete skid pad with a skidding coefficient of roughly 0.3. The second surface consisted of an aggregate asphalt skid pad where the skidding coefficient was approximately 0.5. Slide traction ratings for the nine tires defined in Table 1 are given in Table 2. All evaluations were made using a standard straight grooved tire (ASTM E501) which has a rating of 100 on all of the traction graphs.

In order to determine construction properties alone, ratings at 64 km/h (40 mph) of all three designs on any one carcass were averaged together. These ratings are thought to be representative of any one construction type without regard to the specific design. Ratings for skidding are shown in Figure 2. All three constructions show an improvement in skid resistance on the $\mu = 0.5$ asphalt surface. The simple diagonal constructions seem to be least affected by the different road surfaces, while the belted construction used here displayed the largest improvement on the higher coefficient surface.

Table 1. Matrix of test tire combinations.

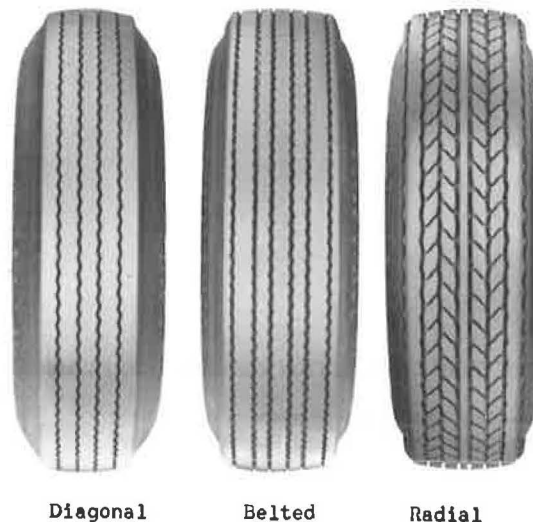
Carcass Construction	Type of Tread Design		
	Diagonal	Belted	Radial
Diagonal	D-D	D-B	D-R
Bias Belted	B-D	B-B	B-R
Radial	R-D	R-B	R-R

Note: 1st letter denotes construction,
2nd letter denotes design

The differences exhibited between different constructions are insignificant relative to the difference any one construction displays on the two different surfaces. On the asphalt surface, all three constructions are essentially equal. The belted and radial constructions are also basically equal on the concrete surface. However, the diagonal constructions on the concrete surface show an apparent advantage.

Partial explanation for this advantage comes from Figure 3. In Figure 3 are the footprint impressions of the nine design tires defined in Table 1. The one footprint of particular interest here is that of the diagonal construction with a radial type tread design (upper right hand corner of Figure 3). The leading edge of this footprint is shaped similar to an arrowhead, with the center of the contact patch considerably longer than the extremities. It is thought that this arrow shape acted to cut through and splash the water away from the tire footprint. This one tire was easily the best of the tires tested for slide on the concrete pad. On Figure 2 this tire (D-R) would have a rating of 112. This rating was responsible for pulling up the average of all diagonal constructions in Figure 2.

Figure 1. Typical tread designs.



To further explore the possibility that one design might be inherently less sensitive to changes in road surface, tests were also run at 97 km/h (60 mph) on the $\mu = 0.3$ and $\mu = 0.5$ coefficient surfaces. The 97 km/h (60 mph) data by basic construction type is shown in Figure 4. As with the 64 km/h (40 mph) data, all constructions show an improvement in skid resistance on the higher coefficient surface. At 97 km/h (60 mph) the three constructions again show relatively little difference on any one surface. The exception here is the somewhat lower averages for the radial constructions. The footprints in Figure 3 can again help to explain the radial tires skidding performance.

Table 2. Straight ahead slide traction ratings.

	$\mu = 0.3$ Pad		$\mu = 0.5$ Pad	
	64 km/h	97 km/h	64 km/h	97 km/h
<u>Diagonal Design</u>				
Diagonal Construction	96	82	103	104
Belted Construction	85	85	106	100
Radial Construction	85	73	103	91
<u>Belted Design</u>				
Diagonal Construction	98	88	100	102
Belted Construction	98	90	105	105
Radial Construction	95	80	100	94
<u>Radial Design</u>				
Diagonal Construction	112	113	112	112
Belted Construction	101	102	106	108
Radial Construction	109	102	106	109
Difference for 90% Confidence Level	5.2	4.9	4.1	3.2

Figure 2. Slide ratings by generic construction type on 0.3 and 0.5 coefficient surfaces at 64 km/h.

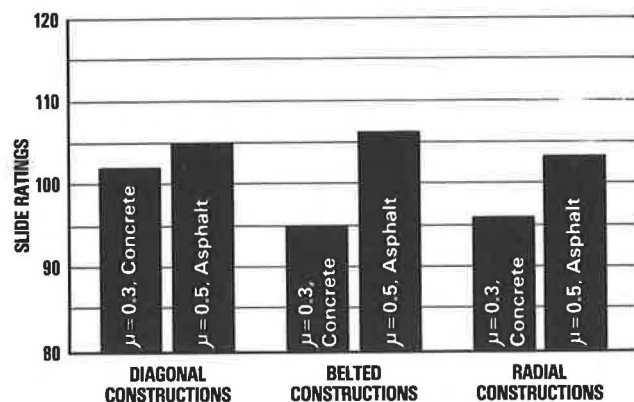


Figure 4. Slide ratings by generic construction type on 0.3 and 0.5 coefficient surfaces at 97 km/h.

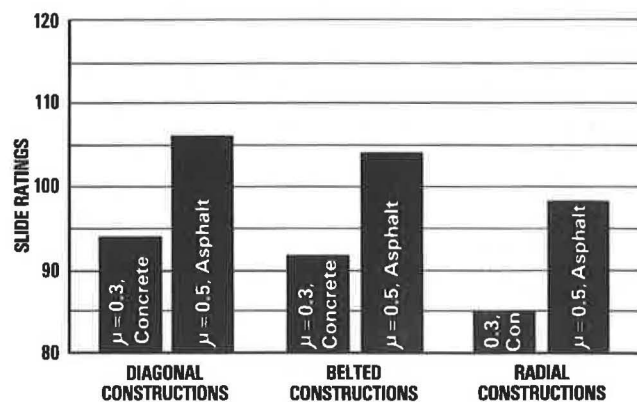
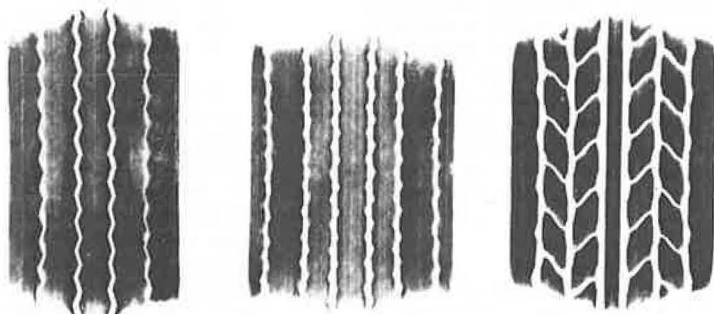


Figure 3. Footprint impressions of the nine tire matrix.

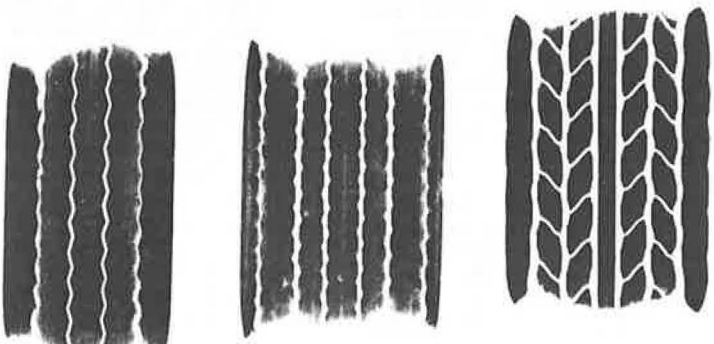
Diagonal
Constructions



Belted
Constructions



Radial
Constructions



The footprint for the radial construction with a diagonal type tread design (lower left hand corner of Figure 3) shows the shoulder rib to be very dark and uniform (high contact pressure). The shoulder grooves here are also very narrow and almost closed in spots. This tire (R-D) only rated 73 for skidding on the $\mu = 0.3$ surface at 97 km/h (60 mph). The radial construction with the belted design (R-B) shows similar footprint properties and had a rating of 80. These "mismatched" constructions and designs significantly reduced the average slide ratings in Figure 4 for the radial construction tires.

It seems, therefore, that no one basic construction type (diagonal, belted, radial) is inherently less sensitive to surface changes than the others.

Carcass Construction vs. Speed

Since most driving situations also encompass a wide range of vehicle speeds, we looked for a particular construction that might remain consistent for traction at different speeds. The two speeds evaluated were 64 km/h (40 mph) and 97 km/h (60 mph), and the data are plotted in Figures 2 & 4.

Essentially, only minor changes in rating were exhibited by all constructions in going from 64 km/h to 97 km/h. The exceptions to this are affected by the same tires that were discussed in the last section. The high rating of the diagonal constructions at 64 km/h (40 mph) on the $\mu = 0.3$ surface (Figure 2) and the low rating of the radial constructions at 97 km/h (60 mph) on the $\mu = 0.3$ surface are responsible for the only significant differences in evaluating speed vs. construction. In all other instances no significant difference exists between the ratings at 64 km/h (40 mph) and 97 km/h (60 mph).

Peak Traction vs. Slide Traction

Up to this point the skidding or sliding traction of the tire constructions has been the main concern. This sliding traction is obviously very important in many traffic situations where a locked wheel or so called panic stop is encountered. However, locked wheel situations are not recommended, and in fact, most decelerations on wet pavement are accomplished without any significant skidding. The ability of a tire to resist skidding can be translated into the peak retarding effort transmitted by the tire before it starts to skid. Peak traction ratings for the nine tires defined in Table 1 are given in Table 3.

The slide ratings for all nine tires at 64 km/h (40 mph) on the $\mu = 0.5$ coefficient surface are shown in Figure 5. These slide ratings seem to be rather scattered. The group of radial type tread design tires holds a slight advantage for slide ratings, but no one construction consistently outperforms the others. The good performance of the diagonal carcass with a radial tread design (D-R) is again thought to be caused by that tire's footprint shape (Figure 3) and pressure distribution.

The peak traction ratings for the same tires and test conditions are shown in Figure 6. Here a slight pattern seems to exist. In all cases the belted constructions (both bias belted and radial) outperform the simple diagonal ply constructions within any one design. The belt under

the tread surface, whether it is on a bias or radial carcass, seems to aid the tire in resisting skidding. It is hypothesized that the belt with its strengthening and stiffening effects holds the grooves open which keeps the footprint more firmly in contact with the road surface, at least until sliding begins.

In comparing slide vs. peak ratings, it seems that tire construction may have a measurable effect on peak traction and that belted and radial constructions outperform their diagonal ply predecessors. Inconclusive data was obtained here on slide traction, although if construction differences influence slide traction, their effects are minor.

The ratings shown in Figure 6 do show another strong pattern. As one progresses from the diagonal tread designs to the belted tread designs and on to the radial type tread designs, the average traction ratings increase. This design related aspect of wet traction performance depicted here was, in fact, evident in all phases of this experiment. It must be kept in mind that the objective of this experiment was to explore tire construction variables and their connection with the wet traction process. The authors do recognize that tread design features are extremely important to wet traction, and this experiment supports much of the data available relating tread design to wet traction performance (3, 4).

Cornering Traction

Construction vs. Tread Design

The same nine tires defined in Table 1 have also been evaluated for their cornering force properties on a wet surface. These tests were conducted at the Calspan Corporation TIRF facility in Buffalo, New York (5). The General Motors short test procedure for Tire Performance Criteria was utilized to obtain cornering coefficients for each tire. The test procedure was modified as follows to obtain wet cornering data for conditions similar to our straight ahead wet traction data.

GM IPC short test procedure except:

1. Speed - 64 km/h (40 mph)
2. Water depth - 0.5 mm (0.02 in.)
3. Surface - 0.5 coefficient
4. Inflation - 165 kPa (24 psi)

The normalized cornering coefficients at 1° slip angle and 87% rated load are displayed in Figure 7. Each group of three ratings represents one typical type of tread design. The benefits of the radial carcass construction (without regard to any specific tread design) are quite evident for these conditions. In all three design groupings, the radial carcass tires generate the highest cornering coefficient. In fact, the three highest cornering coefficients were developed by the radial carcass tires. However, the next best construction group is the diagonal ply tires while the belted constructions displayed the lowest cornering coefficients. The data here is consistent in sorting the three different constructions, although the low values corresponding to the belted constructions appear to be out of place.

Actually, the poor cornering performance of the belted tires is related to the basic design of the test tires. Tires were selected as being typical diagonal, belted, and radial constructions. The variables within any one construction type are numerous, however, and in selecting our base tire constructions it seems that the diagonal

Figure 5. Slide ratings of nine tire matrix on $\mu = 0.5$ surface at 64 km/h.

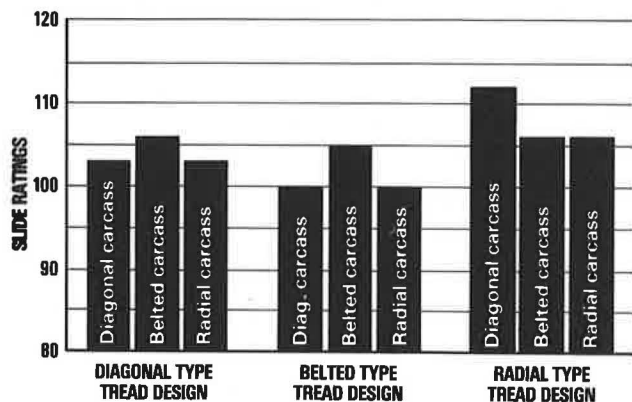


Figure 6. Peak ratings of nine tire matrix on $\mu = 0.5$ coefficient surface at 64 km/h.

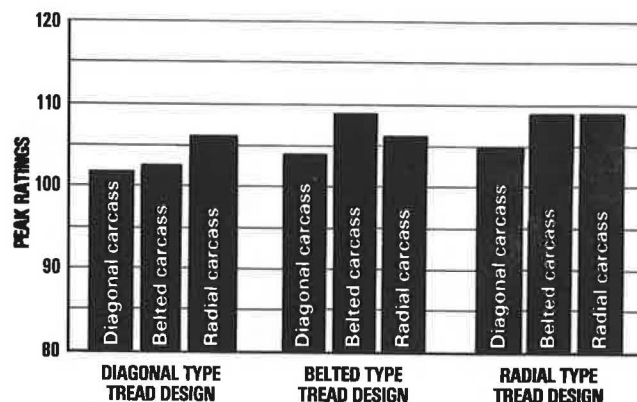
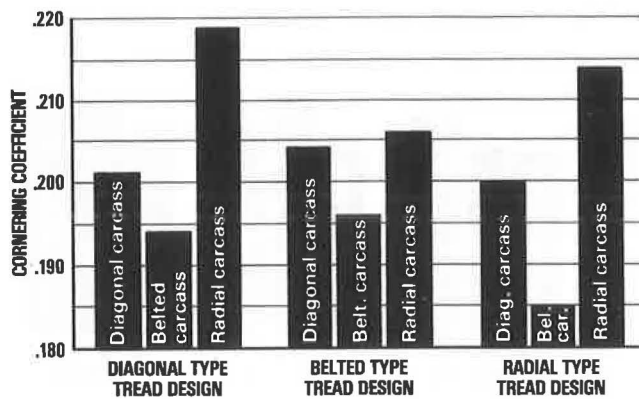


Table 3. Straight ahead peak traction ratings.

	$\mu = 0.3$ Pad		$\mu = 0.5$ Pad	
	64 km/h	97 km/h	64 km/h	97 km/h
<u>Diagonal Design</u>				
Diagonal Construction	105	87	102	100
Belted Construction	106	91	103	98
Radial Construction	104	94	106	99
<u>Belted Design</u>				
Diagonal Construction	108	102	104	105
Belted Construction	106	103	109	104
Radial Construction	109	106	106	104
<u>Radial Design</u>				
Diagonal Construction	110	115	105	108
Belted Construction	107	105	109	105
Radial Construction	119	122	109	114
Difference for 90% Confidence level	3.2	4.2	1.8	3.1

Figure 7. Cornering coefficients of nine tire matrix on $\mu = 0.5$ surface at 64 km/h with 0.5 mm water.



construction used inherently had better cornering capabilities than the belted construction. The cornering capabilities of different generic tire constructions have been studied extensively (6); and the fact that one particular diagonal construction possesses better cornering capabilities than a particular belted or even a radial construction is entirely possible.

The cornering coefficients at low slip angles as shown in Figure 7 also suggest that the tread design has less affect on wet cornering potential than the carcass construction. As previously stated, the largest cornering coefficient difference exists between two different constructions (belted to radial carcass). Looking at any one generic tire construction the three typical tread designs on it show comparatively small differences. The effect of the tread design would probably become more important in wet cornering traction at higher speeds and increased water depths, but for the conditions tested ($\mu = 0.5$, 64 km/h, 0.5 mm water) the carcass construction has a significant influence on wet cornering force.

Construction vs. Slip Angle

Acknowledging the benefits available from different constructions for wet cornering under normal (1° slip angle) conditions, we proceeded to investigate how the different generic constructions performed at higher slip angles. Interest in the higher slip angles developed since loss of vehicle control is often preceded by generation of relatively large slip angles between the tires and the road.

The wet cornering differences for the three generic constructions at 1° and 4° slip angles are shown in Figure 8. The higher slip angles obviously generate higher cornering coefficients for all three constructions. Figure 8 also reveals that all three constructions undergo almost identical increases in cornering coefficient. The radial constructions are again highest in cornering coefficient followed by the diagonal and belted constructions respectively. The same ranking and relative difference is apparent for both slip angles. In regard to our particular investigation, all three generic construction types tested display similar reaction to increases in slip angle.

Construction vs. Load

Variation of vertical load on the tires was also investigated to determine its influence on cornering potential. As with changes in slip angle, all three constructions tested behaved almost identically with respect to changes in load. Figure 9 displays cornering coefficients by construction type for 1° and 4° slip angles and 123% rated load. (Figures 8 and 9 are similar with Figure 8 at 87% rated load and Figure 9 at 123% rated load.)

The higher loads created somewhat lower cornering coefficients for all constructions but the same relationships between constructions remained. The radial constructions again displayed the highest cornering coefficients followed by the diagonal and belted constructions. The difference between 1° and 4° slip angles at 123% rated load reflects the same conclusions that were obtained at 87% rated load.

Figure 8. Cornering coefficients by generic tire construction at 1° and 4° slip angles and 87% rated load.

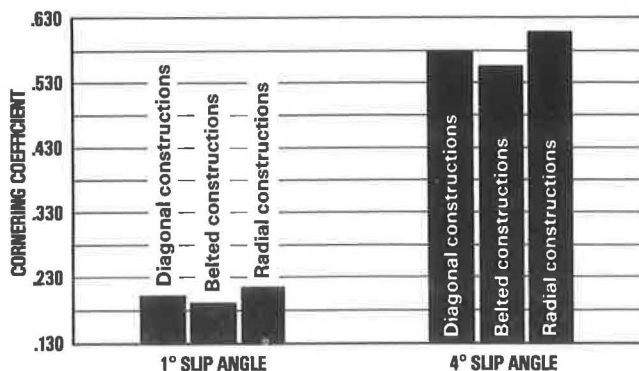
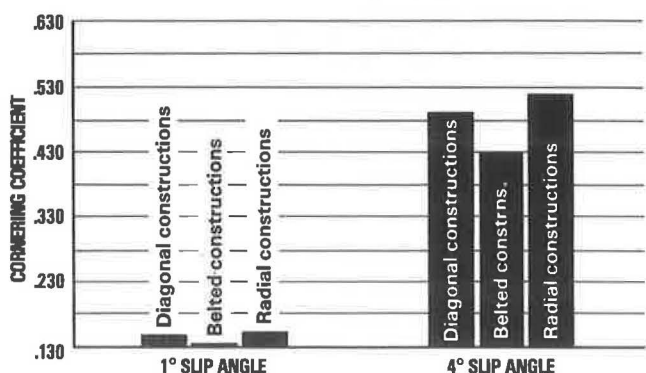


Figure 9. Cornering coefficients by generic tire construction at 1° and 4° slip angles and 123% rated load.



Radial Construction - Belt Variables

Stabilizer Ply - Crown Angle

Investigation of construction variables and their influence on wet traction included testing within the radial construction framework. Tires were first prepared in an HR78-15 size with two steelcord stabilizer plies at angles of 28°, 22°, and 16° with respect to the circumferential centerline. These tires were tested for straight ahead wet traction in the same manner as the nine tire matrix already discussed.

High speed, low coefficient surfaces, and deep water depths are generally good for separating tread design differences. In looking for differences within the radial construction, we used a relatively low speed, a high coefficient surface, and a thin water film in an attempt to neutralize any tread design influence. Therefore, all traction data for variations within the radial construction framework are for 64 km/h on the $\mu = 0.5$ coefficient surface with 0.5 mm water depth. As in all the previous traction graphs, the ASTM E501 standard traction tire has a rating of 100.

A combination of peak and slide traction ratings for the different belt angles is displayed in Figure 10. Effectively all three belt angles provide the same peak and slide traction. The ratings for the 16° belts are slightly lower than the other ratings, but the difference is not significant. The slide ratings are all just slightly better than the peak ratings, but the radial tread design on the steelcord tires must be considered here. The control tire merely has circumferential grooves while the steelcord radials all had a matching radial tread design. The influence of the cross slots in the radial design is believed to help all three of these different crown angle tires for slide wet traction.

Stabilizer Ply - Belt Material

Radial tires are currently available with a variety of stabilizer ply materials. To evaluate different belt materials we prepared GR78-15 size tires with belts of steelcord, fiberglass, and aramid. The constructions were identical in all respects other than the tread ply material. As with the different belt angle tires, these three different belt materials were evaluated for wet

traction at 64 km/h on the $\mu = 0.5$ surface with 0.5 mm water depth.

The variance of belt material in the radial construction had very little effect on wet traction. Figure 11 shows peak and slide traction ratings for the three different belt materials; and no significant difference exists. Once again the slide ratings are all better than the peak ratings, but the radial tread design used on the different belt material tires is assumed to be the reason for this. However, since all of these test tires did have identical tread designs, the close ratings for peak and slide traction provide good evidence that the three different belt materials have virtually no influence on straight ahead wet traction.

Conclusions

1. Tire construction by itself has little effect on skidding wet traction.
2. Tire construction may have a measurable effect on peak wet traction.
3. Tire construction plays a significant role in determining wet cornering potential. However, within any one generic type of construction, a large range of cornering potential may exist.
4. The three typical tire constructions evaluated all reacted in a similar manner to variations in speed, load, slip angle, and surface.
5. Variations of stabilizer ply angle and stabilizer ply material of radial carcass tires have virtually no effect on straight ahead wet traction. The effect of these changes on wet cornering traction is unknown at this time.

The typical radial tread designs in use today contribute more to the wet traction potential of a tire than the radial construction. However, these tread designs are only acceptable for overall tire performance when they are used in conjunction with the radial construction. There are several problems which would exist if a radial type tread design were produced on a diagonal carcass. The main deficiency suspected would be poor mileage to tire wear out. The tread squirm caused by the diagonal carcass would rapidly wear away the open radial tread design. Considering both design and construction parameters, a carefully selected combination of radial construction and radial tread design is necessary to obtain maximum wet traction performance in today's passenger car tires.

Figure 10. Peak and slide traction ratings of a radial carcass construction with 28°, 22°, and 16° belt angles.

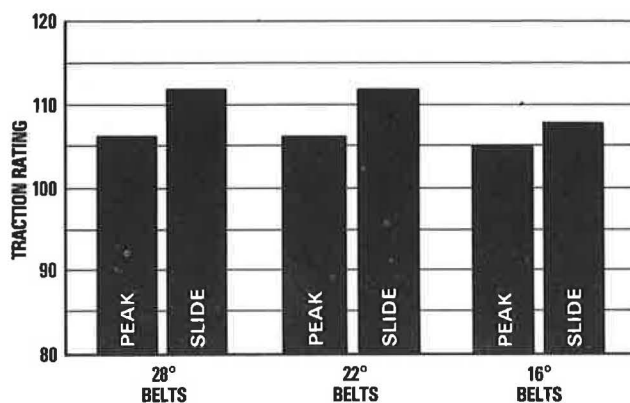
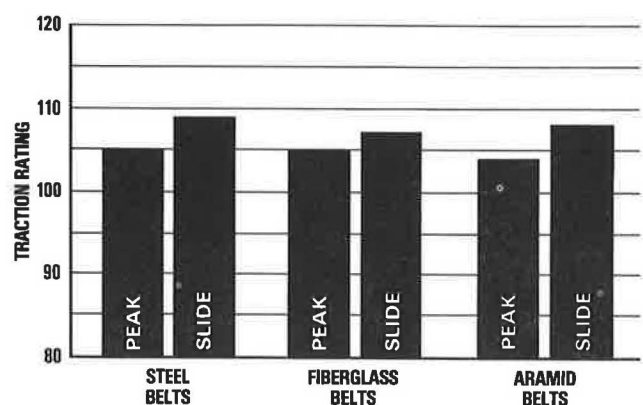


Figure 11. Peak and slide traction ratings of a radial carcass construction with steel, fiberglass, and aramid belt materials.



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