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THE CURRENT ENERGY SITUATION has focused a great deal of attention on fuel consumption. There has been an increasing interest in vehicle fuel economy and the influence that tire rolling resistance can have on overall vehicle fuel consumption.

The major factors which contribute to tire rolling resistance losses may be separated into four general categories: tire design, tire operating parameters, ambient conditions, and highway design. Tire design variables include basic tire generic types, such as bias, bias-belted or radial constructions, along with specific design or material parameters within a given generic type which could affect the tire's rolling resistance performance. Tire operating parameters are those factors such as load, speed, inflation pressure, steer and torque inputs, and operator trip habits, which combine to define a tire's duty cycle. Ambient conditions would be comprised primarily of the effects of temperature and precipitation in a tire's surrounding environment. Highway design parameters include general highway types such as gravel, concrete or asphalt road constructions as well as specific factors like aggregate selection which control final highway surface characteristics.

The categories of tire design and tire operating parameters are areas where significant gains might be made, and typical approaches to the problem of tire rolling losses generally focus on these two categories. Ambient conditions are difficult to control. Therefore, one would not expect to make tremendous gains in this area. The remaining category is that of highway design, and recent studies indicate that certain gains might be available in this area; specifically with respect to road surface texture.

SCOPE

In an effort to develop realistic tire tests and to more clearly understand tire rolling resistance characteristics, a limited study was undertaken to assess the effects of road surface texture. The tests were divided into two parts covering both indoor and outdoor tests. The indoor tests were focused on the differences seen between a smooth steel surface and 3-M safety-walk on a tire dynamometer. The outdoor tests were conducted on a number of roadway surfaces including both concrete and asphalt constructions.

LABORATORY TESTS

Indoor tests were conducted on a standard 67" laboratory tire dynamometer equipped with special instrumentation to accurately measure the applied tire load and the associated rolling resistance force (Fig. 1). The test tire and axle assembly is supported between two force transducers which measure these forces at the axle centerline. The test setup has no capability for applying a driving torque to the test tire and addresses only the free-rolling case with the tire maintained at geometric zero slip and camber angles.

Tests were conducted on a sample of two tires each in 10 different radial passenger car constructions of a given size. Both steel and fiberglass belted constructions were investigated and a number of manufacturers were included. Each test was conducted at 50 mph,

ABSTRACT

Tire rolling resistance losses can be significantly influenced by road surface texture. Data obtained from laboratory tire dynamometer tests and outdoor tests conducted on various paved public type roads indicates that tire rolling resistance losses increase as road surface texture increases. Some tires are more sensitive to surface texture than others, and relative tire comparisons may depend upon the test surface used. Developments in road surface texture may be an additional approach to the question of tire rolling resistance. Other tire performance areas like noise and traction are also affected by surface texture; therefore, future road surface developments should be based on a consideration of the interaction between surface texture and tire performance.

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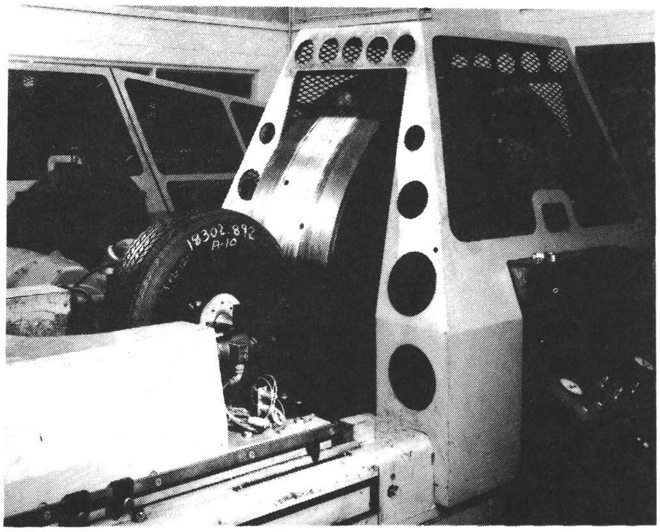

Fig. 1 - Laboratory test equipment

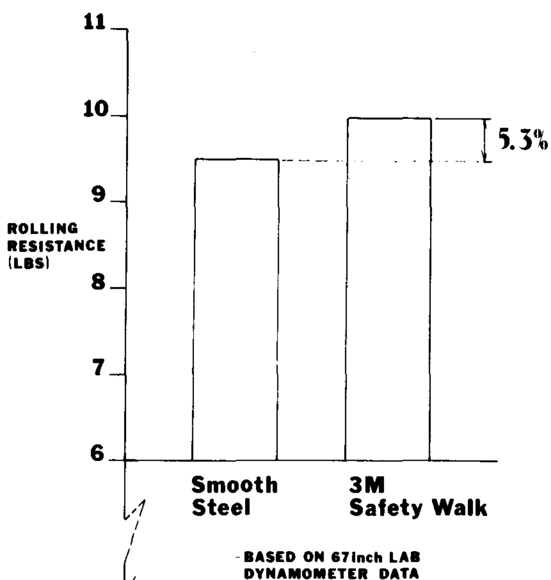

Fig. 2 - Laboratory test results - Tire rolling resistance average surface effects

common load and inflation pressure, with all data taken at steady state conditions.

The tires were tested on a smooth steel drum and baseline values were established. A 3-M safety-walk surface, which has an 80-grit sandpaper-type texture, was then applied to the drum and the tires were retested.

LAB RESULTS - The results revealed that the measured rolling resistance forces were higher in all cases when tested on the textured safety-walk surface as compared to the same tire tested on the smooth steel drum (Fig. 2). The magnitudes of the differences ranged from 2.5% to 11% with the averages being 5.3% higher on the textured surface.

OUTDOOR TESTS

In order to verify the differences observed in the laboratory, and to determine just how much texture effect exists on real-world surfaces, a series of outdoor road tests were undertaken.

Fig. 3 - Outdoor test equipment

The outdoor tests were conducted with a heavy-duty pickup truck specially instrumented to measure tire rolling resistance (Fig. 3). The vehicle is equipped with a single-wheel test fixture cantilevered from the rear of the bed. The fixture is set up to measure the applied load and rolling resistance force on the test tire at the axle centerline as explained for the laboratory dynamometer tests. Load and inflation pressure are controlled from the cab of the vehicle, and test conditions can be changed "on the fly" if desired. Since there is no provision for applying a driving torque to the test tire, this fixture also addresses only the free-rolling case.

The outdoor tests were conducted on a sample of 10 passenger tire constructions. One tire was tested in each construction, and the overall sample was composed of various sizes representing the range of typical usage. Tires were selected from various manufacturers; although the majority were radials, bias and bias-belted constructions were also included.

The tests were conducted at 30 mph, at common loads relative to Tire and Rim Association (T&RA) ratings, and at comparable inflation pressures. Each tire was allowed sufficient warm-up, then was systematically tested over various road surfaces. Each tire was tested twice to minimize test errors.

The outdoor tests were conducted at the GM Desert Proving Ground in Mesa, Arizona, on special test surfaces prepared as reproductions of actual public highways. With the surfaces all being available in one general location, a given tire could be tested from one surface to another based on one common test setup, thus minimizing setup variability. Therefore, any relative differences between surfaces for a given tire should not include variations due to equipment setup.

OUTDOOR SURFACE DESCRIPTION - The various surfaces involved in the study can be repre-

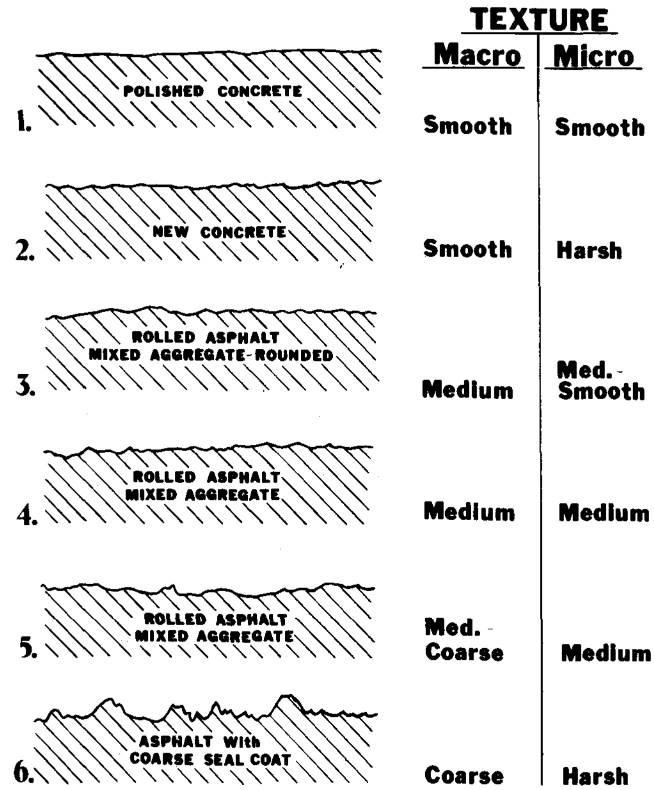

Fig. 4 - Outdoor test surfaces - Test surface description

sented schematically with actual surface profiles determined from representative molds taken at each test site (Fig. 4). In addition, each surface can be loosely described subjectively in terms of the surface macro-texture (large scale asperities) and the surface micro-texture (small scale asperities).

Surface #1 is a special polished concrete surface with smooth macro-texture and smooth micro-texture (Fig. 5).

Surface #2 is a new concrete roadway with a relatively smooth macro-texture; however, with a harsh micro-texture similar to a newly constructed burlap dragged freeway surface (Fig. 5).

Surface #3 is a rolled asphalt surface composed of mixed aggregate with a medium macro-texture and medium-smooth micro-texture. This surface, at least from a subjective standpoint, might be considered an "average type asphalt highway" with random exposed aggregate, rounded due to wear (Fig. 5).

Surface #4 is a rolled asphalt surface similar to surface #3 except that the micro-texture is described as medium rather than medium-smooth, with the exposed aggregate appearing less rounded than that of surface #3 (Fig. 5).

Surface #5 is also a rolled asphalt, mixed aggregate surface, but with a medium coarse macro-texture and a medium micro-texture. This surface is quite similar to surfaces 3 and 4, but with slightly more exposed aggregate (Fig.5).

Surface #6 is an asphalt surface covered with a seal coat of sharp aggregate. The resulting surface is described as having a coarse macro-texture with a harsh micro-texture. This surface is considerably more coarse than typical rolled asphalt highways, however, quite representative of seal-coated type surfaces used on public roads (Fig. 5).

OUTDOOR RESULTS - The results of the outdoor study supported the data acquired in the laboratory tests. The data seems to indicate that the surface macro-texture and micro-texture can both influence tire rolling resistance, with the measured rolling resistance forces increasing as texture increases (Fig. 6). By arbitrarily selecting the new concrete surface as a reference and normalizing the data to that baseline, direct surface comparisons may then be made, independent of tire size or absolute rolling resistance values.

If we consider only surfaces 2 thru 5, which might represent typical primary public highways, an average of 8% difference in rolling resistance was seen between the new concrete baseline and the most textured rolled asphalt surface. However, if we look beyond the primary type highways, the seal-coated asphalt surface produced average rolling resistance values 33% higher than the baseline while the polished concrete showed a 12% reduction.

The point which should be noted is that a definite effect of surface texture can be seen in tire rolling resistance, with losses increasing as texture increases, and average differences of 30% or more existing on hard-surfaced public roads. A limited number of tests have also been conducted on non-paved roads, with the results indicating that rolling resistance forces on typical public graveled roads may be more than twice as high as those measured on the baseline surface.

RANK-ORDERING

An interesting point that was observed in both the road and laboratory tests is that all tires do not respond in identical fashion to surface changes, with certain tires being more sensitive to texture than others.

As outlined earlier, a difference of about 5% was seen in the laboratory between a smooth steel surface and 3-M safety-walk. However, if we look at the performance of the individual tire samples, the differences ranged from 2.5% to 11% in the extreme cases (Fig. 7). The significance of this factor is that tire comparisons or rank-orderings could be dependent upon the test surface used.

RELATED PARAMETERS

If highways were designed specifically for optimum rolling resistance performance, the results of this study would indicate that smoother surface textures are advantageous. However, there are other tire performance areas which are also important to the user. In addition to rolling resistance, certain tire per-

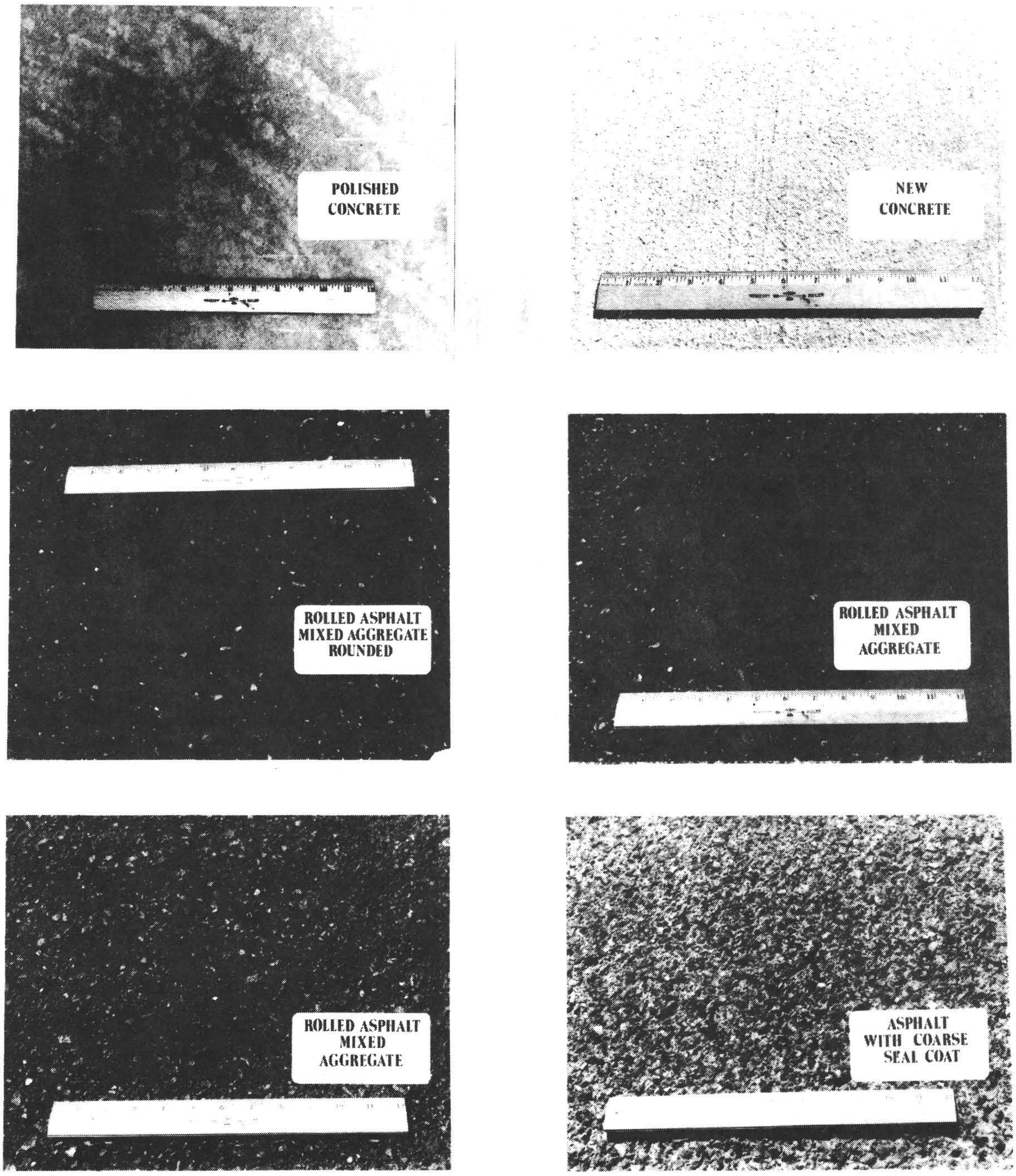

Fig. 5 - Outdoor test surfaces - Pavement test surfaces

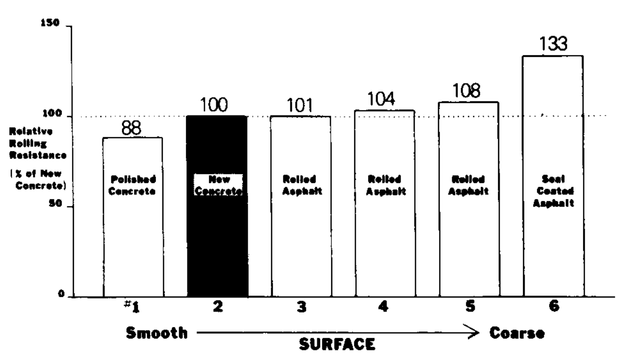

Fig. 6 - Outdoor test results - Tire rolling resistance versus pavement surface texture

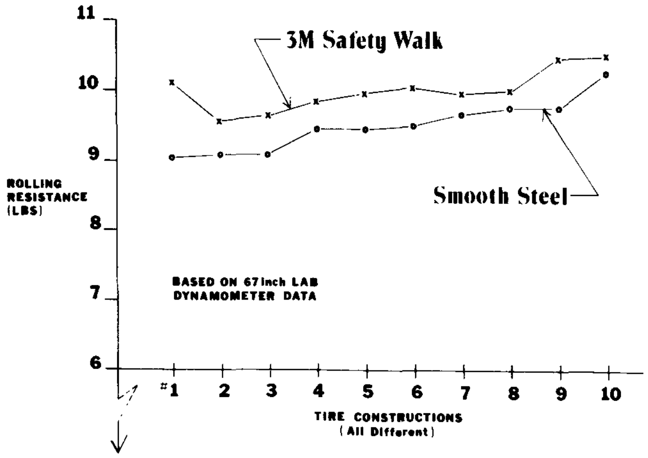

Fig. 7 - Surface effects on rank order - Tire rolling resistance

formance areas which may be influenced by surface characteristics are pass-by noise levels, traction performance and tread wear. Although the topic of tread wear will not be addressed in this paper, a few comments can be made regarding pass-by noise levels and traction performance.

PASS-BY NOISE LEVELS - In a paper by D. B. Thrasher, R. F. Miller and R. G. Bauman (1)*, data was shown indicating that pass-by noise levels increase as road surface texture increases (Fig. 8). The test roads were all hard-surfaced including one black-top and three concrete constructions with differing degrees of surface texture. Differences in the pass-by noise levels between 7 to 10 db(A) can be seen from the smoothest to roughest surface. Fortunately, it appears that, similar to rolling resistance performance, pass-by noise levels improve as texture decreases and that smoother surfaces would be in the right direction for both.

TRACTION - Any move toward smoother pavement textures, as we know them today, however, would be in the wrong direction if wet traction performance is considered. In a paper by J. L. Beaton (2), data indicates that wet traction performance is significantly affected by pavement surface texture (Fig. 9). It appears that both macro-texture and micro-texture are important and that wet traction performance increases as surface texture increases.

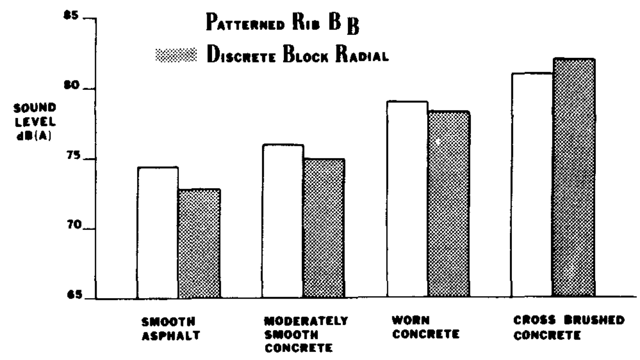

Fig. 8 - Pavement texture effects on passby noise levels - Influence of pavement texture on peak passby noise levels (Ref. 1)

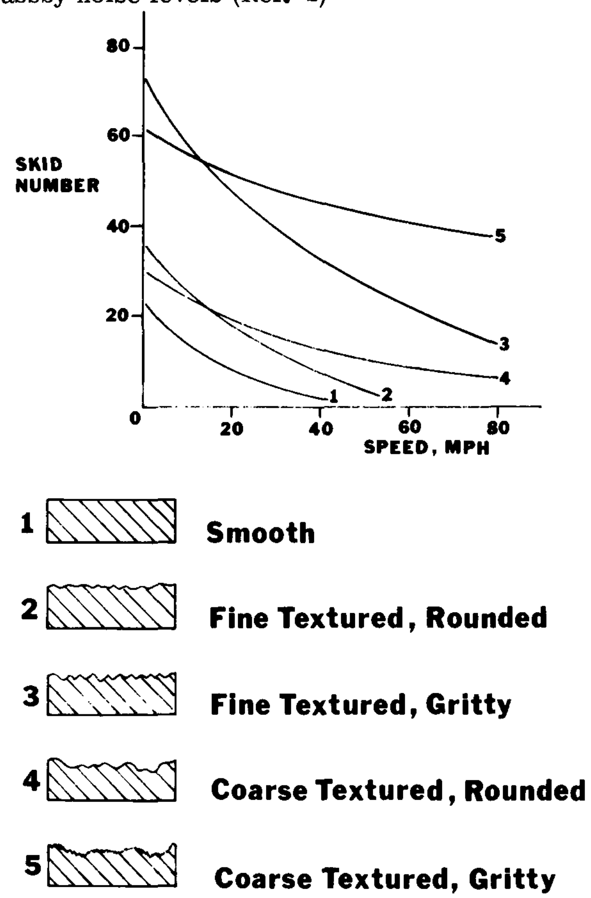

Fig. 9 - Pavement texture effects on wet traction - Pavement surface textures effects on wet traction (Ref. 2)

HIGHWAY DEVELOPMENT

It appears that we are faced with a compromise between rolling resistance, noise, traction, and perhaps tread wear when considering highway designs, surface treatments or surface maintenance.

The results of work published by J. C. Walker of Dunlop Limited (England) (3) indicates improvements in both noise and traction performance on a surface development which they call "Delugrip". Later indications are that rolling resistance performance is also improved. Apparently it is possible to develop surfaces which might be beneficial from the standpoint of rolling resistance, noise and traction performance without severely compromising any of them.

*Numbers in parentheses designate References at end of paper.

SUMMARY

The results of both the laboratory and outdoor tests show an effect of increased tire rolling resistance with increasing surface texture. Although some tires were more surface sensitive than others, average rolling resistance differences of 5% were seen between smooth steel and 3-M safety-walk in the lab, while the outdoor data indicates rolling resistance differences of 30% or more on hard-surfaced public roads. Differences of 8% were detected on primary type highways alone. Rolling resistance differences of this magnitude are quite significant, and an important point is that any improvements which can be made through surface design would apply to all tires in the marketplace, and not only those future tires developed with rolling resistance as a design parameter. However, it has been shown that surface texture can also influence tire noise and traction performance. Therefore, any surface texture approach must be based on an overall consideration of all the related tire performance areas.

Clearly, there is no single solution to the question of tire rolling resistance, but the final gains will be a combination of advances made through various approaches. The data presented here suggests a possible approach through road surface technology, and additional effort in this area might produce meaningful returns.

First of all, the work outlined here is really only a beginning. A much more detailed effort is required to more completely understand the interactions between road surface characteristics and tire rolling resistance, and how these interactions may also relate to other tire performance areas.

Secondly, the results of investigations into tire and roadway interactions should be applied in a coordinated effort to develop road surfaces designed through an approach based on inputs from both tire and highway engineers.

Finally, additional work is needed to sufficiently correlate the results of laboratory tests with real-world performance to insure that the tires developed on today's laboratory tests are evaluated on equipment and surfaces which will realistically represent the tire's performance on public highways tomorrow.

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