Contribution of the Rubber Compound to the Wet Skid Resistance of Tires

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•OUR firm has continuing research programs directed toward understanding factors that will improve the skid resistance of tires. The work reported here represents part of the research effort being conducted to understand the effect of rubber compositions on skid resistance.

Only the major interactions which occur between road surfaces and rubber compounds and the properties of the compounds which offer a major contribution to the coefficient of friction are discussed in this paper. Emphasis is placed on the practical aspects of skid resistance which are the concern of every driver, rather than extreme conditions infrequently encountered in normal driving. The contributions of tires to skidding in these instances are usually minor compared with other aspects of the problem, whereas there are extremely important and commonly occurring situations in which the tire can make a major contribution.

Thus, we will omit reference to snow and ice, to dry skids, and to hydroplaning. Snow and ice are frequently encountered in northern areas, but two factors make them constitute a less urgent problem for our immediate concern than that of skid resistance on wet pavements above freezing. First, coefficients of friction are normally very low, drivers are aware of the dangers, and they are more likely to take appropriate precautionary efforts. Second, because of the low coefficients, mechanical devices are usually required for maximum traction, and the contribution to friction which the tire alone can make is small.

Long skids on dry surfaces also represent a situation to which the tire can make only small contributions. Available coefficients with tire materials on a paved road surface range between 0.8 and 1.0. Accidents involving dry skidding as a primary factor, therefore, have driver error as a major component.

There has been considerable recent discussion of loss of control by hydroplaning. For passenger cars this requires a special combination of circumstances, including an element of driver carelessness. It is probably more related to tire design than tire compounds and has been given less consideration in this portion of the work.

In the course of ordinary driving almost every driver will frequently encounter wet pavements. Records at the Newark Airport Weather Station are probably representative of most of the highly populated northern and eastern parts of the country, and so indicate the frequency with which drivers will be driving on wet pavements. At Newark, rain falls on an average of 122 days out of the year. On these days approximately 25 percent of the time represents actual periods of rainfall, and it is reasonable to assume that pavements are wet at least twice this long. Thus, a large proportion of drivers in this country are driving on pavements that are wet a substantial part of the time. On such pavements friction coefficients of tires can be, and frequently are, much lower than the friction coefficients available when the same pavement is dry. Our own data indicate that coefficients may be found as low as 0.25 on suburban streets and 0.4 on major highways at low speeds.

One of the major elements of concern for vehicles moving on wet roads is that drivers appear to be unaware of the loss in available coefficients and so drive at very nearly the same speeds that they drive on dry pavement (Fig. 1). This situation clearly

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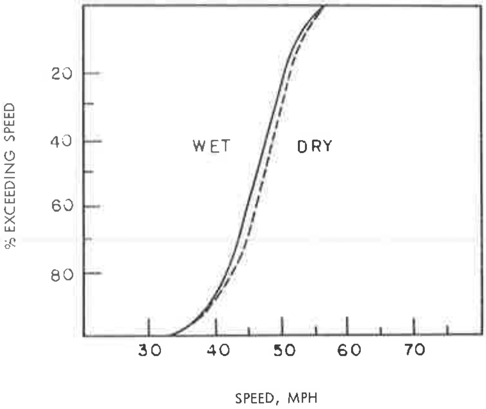

Figure 1. Speeds on a rural curve in New York State.

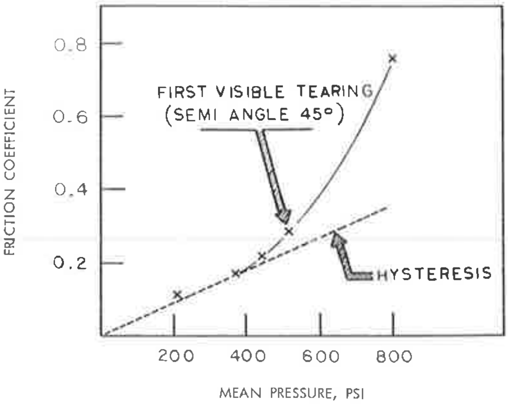

Figure 2. Lubricated friction of cones sliding on a rubber surface at very low speeds. The calculated contribution of hysteresis to friction is shown by the dashed line.

puts a heavy demand on the contribution of the tire to wet skid resistance, and therefore we have included only wet surfaces in this research.

Our studies of the properties of tire compositions and their effect on wet friction have been greatly facilitated by the development of the portable skid tester at the British Road Research Laboratory. This instrument was described by Giles, Sabey, and Cardew (2) at an ASTM symposium in 1962. In agreement with results in England (3), we find there is very good correlation between locked-wheel sliding of vehicles on actual slippery roads and laboratory tests with the portable tester on appropriately chosen surfaces. We have used this instrument extensively in our work.

ROAD SURFACES

With a background established for considering factors involved in wet friction of tires on roads, we can examine what these factors are. Since the surface of the road on which the tire moves determines the range of wet friction coefficients available, it is important to know the features in that surface contributing to friction in order to be able to study intelligently the contribution which tire compounds can make. Firm quantitative ideas about this can be traced to the important early work of Tabor (4, 5), amplified by the extensive studies at the British Road Research Laboratory (3).

It has been recognized for many years that an essential characteristic of slippery roads is that the aggregate exposed at the surface has been polished by the passage of traffic (3). Recent progress has come with the recognition that it is possible to make reasonably quantitative estimates of the state of the road surface without reference to its previous history.

The contribution of the road surface to the wet friction coefficient may be conveniently considered to consist of two parts: a deformation component and an abrasive component (6). The deformation component is contributed by the relatively large-scale irregularities in the road surface, with root-mean-square elevation of 0.01 in. or larger. The abrasive component is contributed by a finer scale roughness with acute angular projections at the surface.

These two components of a surface appear to be sharply distinguishable experimentally by evaluating the friction of rubber materials of low and high hysteresis. The deformation component contributes more to friction in a high-hysteresis rubber and very slightly to friction in a low-hysteresis rubber.

Figure 2 shows that this difference can be demonstrated very simply in the laboratory. According to these data there is a critical apex angle at which a cone will tear a rubber surface as it slides over it, even with a lubricant. Tabor (5) pointed out in 1958

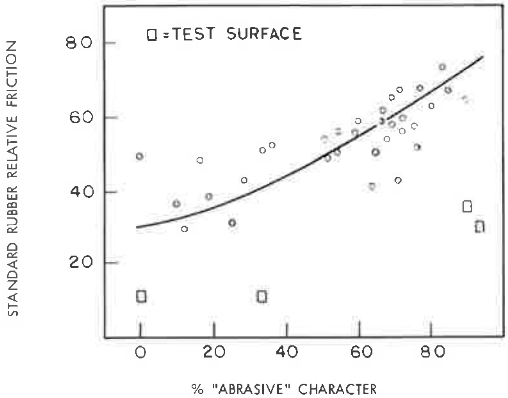

Figure 3. Character of roads in two suburban New Jersey communities. Friction less than 50 represents a slippery surface.

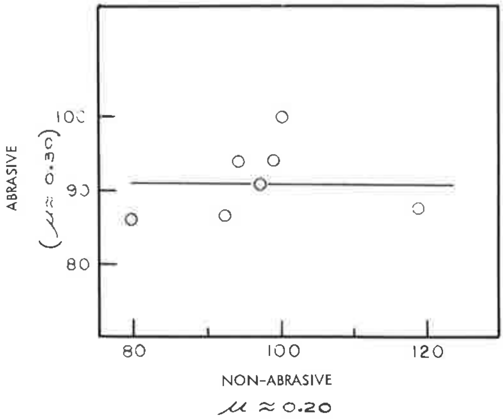

Figure 4. Relative friction on low-coefficient surfaces.

that the experiments of Sabey (7) at much higher sliding speeds, characteristic of those which might be encountered by tires, fall into a very similar pattern.

This laboratory demonstration lends confidence to an empirical procedure which has been developed in our laboratories for analyzing actual road surfaces. By measuring the lubricated friction of two rubber samples with a wide difference in hysteresis (8), we can separate the components of a road surface in a reasonably quantitative way. The friction of the high-hysteresis rubber is determined by both components, whereas that of the low-hysteresis rubber is primarily determined by the abrasive component; therefore, that portion of the road surface friction contributed by the deformation component is a function of the difference between the coefficients of friction of the low- and high-hysteresis rubbers.

Figure 3 shows this relation for a number of roads (6) in northern New Jersey which have been roughly rated as slippery or nonslippery by local highway patrol officers. In the same figure are plotted data for typical test surfaces used in the laboratory in studying rubber friction.

The ordinate represents "skid resistance" (2) of a standard rubber sample, which is approximately proportional to the coefficient of friction. A value of 50 represents a road marginal for skid resistance. The abscissa represents the percent abrasive character of the surface. Test surfaces shown in the figure as having 0 and 90 percent abrasive character are, respectively, wavy glass and a terrazzo surface occasionally used for testing tires for skid resistance.

It follows from these data that an important aspect of tire friction on wet slippery roads is the behavior of rubber tread materials on superficially rough but nonabrasive surfaces, where hysteresis plays a dominant role. On such surfaces physical properties of the tire tread which can be measured in a laboratory determine absolutely the relative friction differences between tire materials. These properties are derived primarily from the polymer used in the tire, and secondarily from the other ingredients which go to make up the final vulcanizate.

The choice of hard surface for testing rubber is important, as may be obvious from the preceding discussion, but this has not always been taken into account. Thus, Bassi (9) used porphyry and terrazzo tiles because he found asphalt to be abraded by the rubber specimens. Briggs, Hutchinson, and Klingender (10) and Aarbach, Hallman, and Brunot (11) used ground glass without discussing in detail reasons for the choice. Our experience indicates that there could be poor correlation between significant variables and wet skidding resistance of tires caused by the surface chosen for testing. For example, there are a number of statements in the literature that hardness is positively correlated with skid resistance (2, 10, 12). On actual slippery roads the correlation is

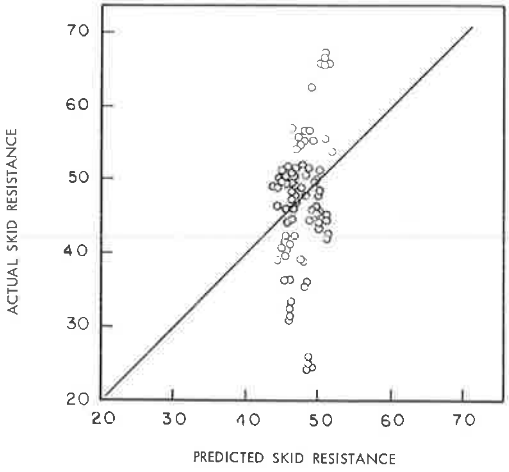

Figure 5. Hardness alone as a predictor of wet skid resistance.

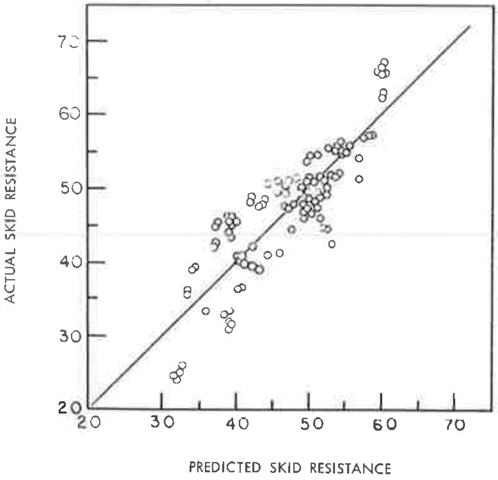

Figure 6. Resilience alone as a predictor of wet skid resistance.

negative, and we find a positive correlation only on abrasive surfaces. Roads which are highly abrasive are rarely slippery. Generally speaking, any test surface which depends on abrasiveness for friction will give results which are relatively poor for evaluating practical tire tread materials. This is especially true for low-friction test surfaces.

A typical example is shown in Figure 4. The relative friction of a number of tire tread materials on a low-coefficient abrasive surface is compared with that on a low-coefficient nonabrasive surface, both tested with the laboratory tester (13). The latter correlates with tire performance on an actual road; the former does not. The non-abrasive surface offers a means of discriminating between compounds which relates to actual road surfaces.

RUBBER COMPOUND

Skid resistance is a property of the tire tread composition, and no general statement about specific components can be made without considering the composition as a whole. Rubber, oil, and black are the most important constituents, and their ratios determine properties. Fine details of the nature of the carbon black filler, of the hydrocarbon extender, of the method of vulcanization, or of many other variables in compounding have small effects on wet friction. They can usually be neglected in considering skid resistance of tires.

Two properties, hysteresis (as measured by rebound resilience) and modulus (Shore A hardness), determine the relative friction of a rubber composition on a typical slippery road within the experimental error. A linear combination of these properties will predict with a very high degree of accuracy the relative friction of two tire materials on a surface (4).

Figures 5, 6, and 7 illustrate this for a surface typical of actual slippery roads.

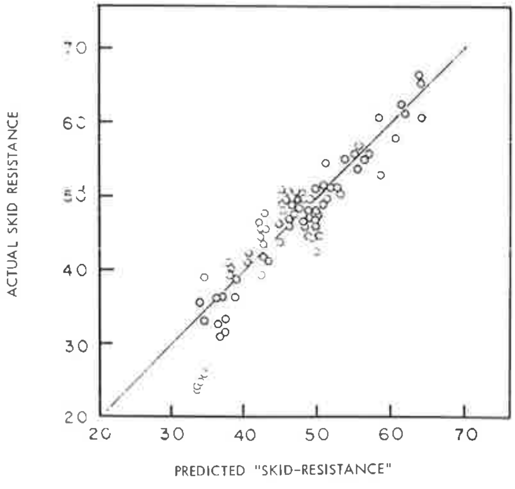

Figure 7. Combined resilience and hardness as predictor of wet skid resistance.

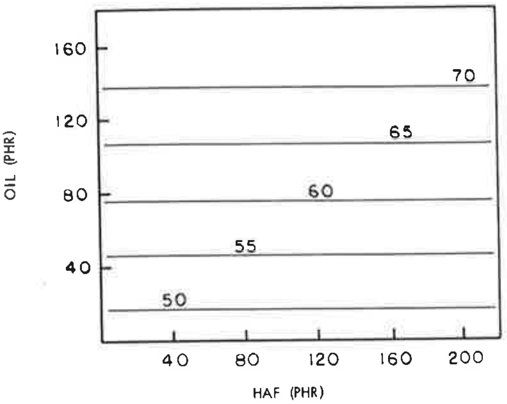

Figure 8. Friction of SBR compounds on a standard road surface as a function of oil and black (HAF) in parts per hundred rubber in the compound. Numbers on the lines are "skid resistance" units.

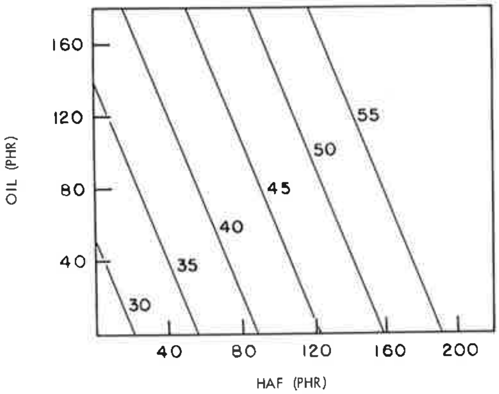

Figure 9. Friction of polybutadiene compounds on a standard road surface. Numbers on the lines are "skid resistance" units.

Figure 5 shows that modulus (hardness) is poor as a predictor alone. Predicted values are those obtained from a least-squares fit of the data. Figure 6 shows that resilience is much better in predicting relative wet friction, and finally Figure 7 shows that, taken together, they give a very high accuracy of prediction. The correlation coefficient for these data is over 0.90, indicating that 80 to 90 percent of the variance in the data is accounted for by hysteresis and modulus.

Glass transition temperatures of rubber and of oil may limit the friction coefficients obtainable from any given combination. The difference between glass transition temperature and service temperature and the form of the damping curves as a function of temperature are related to resilience at the speeds important for skid resistance.

We can show quite clearly by Figures 8 and 9 that the entire composition must be considered, rather than individual components alone. The figures show effects of variation in composition of tire tread stocks made from two commonly used elastomeric materials on wet friction on an actual road surface. With the first material, SBR (Fig. 8), the filler has a negligible effect on skid resistance over a wide range of concentration. This is because of the coincidence that carbon black changes the two important physical properties in opposite directions so as to balance their overall effect on skid resistance. Figure 9 shows that friction of the much more resilient polybutadiene is affected by carbon black as well as by oil, because in this instance carbon black changes the hysteresis of the mixture so much more markedly than it does hardness that it has a significant effect on wet friction.

SUMMARY

1. Friction on road surfaces arises from deformation and abrasion components which can be separated quantitatively by laboratory tests.

2. Slippery surfaces have a high percentage of deformation component.

3. Hysteresis and hardness of tread stock compounds predict skid resistance on slippery roads with a high degree of accuracy.

4. The second-order transition temperature sets practical limits on friction coefficients that can be obtained for a given rubber. However, major compounding ingredients (oil and black) change the hysteresis and modulus of tire rubbers in different ways, so the compound must be considered as a whole.

ACKNOWLEDGMENTS

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