# Friction and Slipperiness

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•THIS discussion is limited to aspects of the tire-pavement friction problem in which hydroplaning does not take place, either because the water layer on the pavement is too thin, or the drainage channels permit ready escape of the water from the contact area, or the speed is low. Under these conditions friction is almost entirely due to adhesion and hysteresis losses in the tread rubber. Wear of the tire or of the pavement involves insignificant contributions to the energy exchange in friction, certainly under wet conditions, and will therefore be ignored here. The pavement is considered as being perfectly rigid.

## THE NATURE OF RUBBER FRICTION

The adhesion component of friction is due to the making and breaking of atomic junctions between the rubber and pavement surfaces while the hysteresis component is caused by losses within the bulk of the tread rubber. Kummer (1) has shown that both phenomena are different manifestations of the same property of the rubber, namely of its viscoelasticity.

A viscoelastic material can be represented by a system of springs and dampers and, although there is still uncertainty about details of this model, it is not difficult to visualize how bulk deformation of the rubber leads to hysteresis losses and that these are related to the damping properties of the system. Kummer has shown that the making and breaking of the junctions, as the rubber slides over the pavement, involves essentially the same processes as occur in bulk deformation. First, the surface molecules of the rubber form junctions with those of the pavement. Then, as the sliding continues the molecules are stretched until the junctions finally break, and the molecules spring back. Thus we are dealing here with a deformation process of the same general nature as that which leads to the hysteresis losses.

The damping characteristics of viscoelastic materials are strongly frequency- and temperature-dependent. At a given temperature, damping will be at a maximum at a definite deformation frequency of the bulk and of the surface molecules of the rubber. If sliding speed is related to frequency, it is not probable that the adhesion component would peak at the same speed at which the hysteresis does, and indeed it does not. The adhesion peak occurs at sliding speeds of around 0.1 mph and the hysteresis peak at 1000 or more times this value.

Relating friction quantitatively to the damping characteristics of the rubber is a complex undertaking. It requires separating adhesion and hysteresis. Theoretically this can be done by using a perfectly smooth surface in one case and a perfectly lubricated, rough surface in the other. In practice this is quite difficult to do and usually can only be approached. Another difficulty is the temperature dependence of both damping and friction, particularly since the energy expended is converted into heat of which a significant portion goes into the rubber. Much of our research is directed toward obtaining answers to these problems, particularly for the conditions which prevail in the case of a tire sliding on a pavement.

One important characteristic of the damping properties of viscoelastic materials is the fact that the damping peak shifts to another frequency without changing its magnitude

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as the temperature changes. By this method, it is possible to obtain the effect of a wider frequency range than can be provided by the test equipment at hand. Explaining friction in terms of deformation frequency implies that the adhesion and deformation peaks of the friction curve should behave as the damping peaks do. For selected conditions, at the adhesion maximum, this has been demonstrated to hold true (2). Preliminary evidence indicates that it is also true for the hysteresis peak (3), although we have not been able to reach the necessary sliding speeds as yet.

## PRACTICAL CONSEQUENCES OF THE FRICTION THEORY

Although we now understand the most important aspects of the mechanism of rubber friction more or less in a qualitative manner only, a number of practical applications to the tire-road friction problem are possible. The tire presents, of course, a much more complex situation than a simple rubber block does. One manifestation of this is that a sliding tire exhibits the adhesion peak at higher speeds than a rubber block. This is caused by the temperature increase which occurs in the contact area. A temperature increase causes the damping and, therefore, the friction peaks to occur at higher speeds. When the tire is slipping, the peak occurs at still higher apparent rates of sliding in the contact area. This can be explained by the discrepancy between the sliding speed computed from the measured wheel slip and the true sliding speed. The tread of the tire behaves like the bristles of a brush that is being moved across a small obstacle; on passing over the obstacle the bristles are deflected backward and slide over it at a speed less than that of the brush. Behind the obstacle they snap forward to resume brush speed and their normal position.

Tire performance is also influenced by tire construction and inflation pressure. These determine the pressure distribution and the parasitic motion of the tread elements in the contact area. On a vehicle, suspension geometry and dynamics superimpose further parasitic motions on those already present in the contact zone.

Normally the skidding or sliding tire operates somewhere between the adhesion and the hysteresis peaks. Although the peaks shift toward higher speeds with increased temperature, the effect of a temperature change on the skid resistance at a given speed cannot be predicted with certainty unless considerable information is available. When the hysteresis contribution is relatively minor, a temperature increase would cause the skid resistance to increase because the tire is operating to the right of the adhesion peak on the descending branch of the total friction curve. The temperature increase causes the peak to shift closer to the operating point; hence the latter is higher up on the curve. When hysteresis is predominant, the opposite will occur. Clearly all kinds of combinations are possible, depending on rubber composition, speed, temperature level and change, and whether the tire is operating on a surface producing high adhesion or hysteresis. The prediction of the temperature effect is further complicated by limited information on what role air, pavement, water and initial tire temperature play.

The temperature dependence of tire friction is of particular importance in friction surveillance programs of highway systems. These usually involve measuring the same pavement at intervals of many months and consequently at different temperatures. Pavement friction is subject to change from many causes. The changes cannot be detected nor long-term trends be ascertained unless individual measurements are normalized for temperature effects. Thus ASTM Method E 274 for skid-resistance measurement by locked-wheel trailer should eventually include a temperature correction procedure. This, however, requires the cooperation of all those agencies which operate skid trailers, if only to determine what the range of the error is if no correction is applied. The same applies of course to all testers, whether using full-scale tires or not.

## HYDRODYNAMIC EFFECTS ON TIRE FRICTION

At speeds above 30 mph, hydrodynamic effects begin to make themselves felt. Intrusion of the contact area by water begins. This effect is reasonably well understood. It accounts for the decrease of the friction on wet pavements with speed. We know less about what occurs on a wet pavement at lower speeds where friction is still speed-dependent. Though the bulk of the water has been displaced from the contact area, are there small fluid wedges being formed on individual asperities of the pavement as has been suggested? Is a hydrophobic surface to be preferred to a hydrophilic one? Different opinions exist on this point. There are other questions which require answers before we fully understand the mechanism of tire-pavement friction.

## PAVEMENT FRICTION MEASUREMENT

Skid-resistance control is primarily a safety measure, but is skid resistance really the parameter which governs the frequency of out-of-control accidents on wet pavements? Wheels are locked after an emergency has arisen, but loss of control can occur because rolling wheels can no longer transmit the forces which are imposed on them. Therefore it may well be just as important to know what the maximum force is that a tire can transmit in slip as when it is locked. Pavement characteristics do influence the ratio between the two friction values.

We are planning to learn more about the characteristics of slipping tires and are therefore modifying our road friction tester which up to now was capable of measuring locked-wheel friction only. We decided that we should measure in transient slip, that is, as if gradually more braking force is being applied. In fact we plan to do just this and let the wheel pass the critical slip (at which friction is at a maximum) and release the brake before or after the wheel has locked. We believe we have a solution which will permit us to obtain the momentary friction force directly, without having to compute it after the test.

## MINIMUM SKID-RESISTANCE REQUIREMENTS

For the time being, however, only skid-resistance data are available to highway engineers and skid resistance is all that agencies will be able to measure for some time to come (and this may well remain the best method for pavement surface characterization). The question arises: what skid-resistance values make a pavement safe or unsafe and what minimum values should be tolerated? The obvious solution is to go to accident data for an answer and this has been done here and in Europe. Actually, accidents are statistically rare occurrences (particularly those of a specific type) and, except for selected projects, accident reports are quite unreliable at the present state of the art.

We therefore looked at whether or not it would be feasible to derive minimum skid-resistance requirements from the needs of traffic. One may reason that the minimum skid-resistance requirements are those which permit normal traffic under normal conditions to move safely. For instance, one can postulate that pavement skid resistance is acceptable if it permits the maximum decelerations which are used habitually by drivers in the absence of an emergency. Similarly, one can use lateral accelerations for defining the frictional requirements on curves. Since on wet pavements skid resistance is strongly speed-dependent, speed is a most important parameter in this approach and the minimum requirements will vary with the prevailing traffic speeds.

We believe that by taking this approach we have been able to arrive at minimum skid-resistance values which, if adhered to, will make the nation's highways on the average considerably safer than they are now. A comparison with available accident vs skid-resistance data indicates this (4). Nevertheless, even though our approach may rest on a firmer basis than derivation from accident data alone, more solid data on the characteristics of normal traffic are needed. How do drivers approach a stop sign? What decelerations are used on limited-access highways? And so on.

## THE POLISHING OF PAVEMENTS

I have touched earlier on some problems connected with the measuring of skid resistance, but if a standard for minimum skid-resistance values would be adopted, how would an agency responsible for complying with the standard go about assuring that the standard is met?

Of course, pavements with skid-resistance values below the prescribed standard can or must be resurfaced. This method, even with the most lenient standards, can become quite expensive if the new surface loses its skid resistance rather rapidly again.

Pavements are polished by traffic. The rate at which different aggregates polish varies, and the eventual polish at which the pavement stabilizes varies. Empirically each highway department has a fairly good idea about which available aggregates polish more and which less. It is, however, important that we learn which properties make a mineral a poor or a good risk for use in a surface course so that compliance with a standard can be predicted and cost comparisons between different available solutions can be made.

Before procedures of this type are feasible we need to know a great deal more about pavement polishing than we do now. Polishing is the consequence of wear, although the relationship between the two is not necessarily a constant one, even for a single material. It is influenced by all sorts of factors. For instance, studded tires may wear down a pavement, but they can increase its skid resistance. In fact, every winter rejuvenates the pavements in the northern states to varying degrees, whether studded tires are permitted or not. Even a long-lasting rain can raise the skid resistance of certain pavements by a measurable amount.

Traffic, as such, does not polish a pavement. We have run a tire against a drum to which aggregate particles had been glued and found virtually no polishing as long as no abrasive was applied. An abrasive is a prerequisite for polishing. We use a carefully selected and tightly controlled abrasive for our laboratory wear tests and obtain results which are in general agreement with field experience.

We are, however, not sure if the abrasive which we are using is realistic in combination with all pavement materials. To make the correct selection we should know more about the characterisitcs and the sources of the dust on the highways. The nature of the dust changes with the weather and the seasons, and this change may account for the observed variations of the skid resistance.

## THE POLISHING PROCESS

Studies on the wear of mineral aggregates have shown that wear produced by a sliding rubber block causes scratches and pits on the flat surfaces of the mineral particles. The amount of wear is not clearly related to any single characteristic, but the hardness of the mineral is an important factor.

Interestingly, minerals are worn by an abrasive consisting of the same material. A very fine polish can result from this combination if the abrasive particles are small. Not much roughening occurs if subsequently coarser particles are introduced, but when the particles are harder than the aggregate they cause rapid roughening. Much more needs to be known before the wear and polishing processes on the highway are fully understood and can be described in quantitative terms.

A parallel line of investigation deals with the problem of how the various properties of individual aggregate particles influence friction. One such property is the microroughness of that portion of the particles which comes into contact with passing tires. There are indications that above a certain microroughness friction is independent of roughness, while below a critical value the friction decreases with decreasing roughness (when the surface is wet). We have been able to confirm this under laboratory conditions. One difficulty we encountered is that we did not find a satisfactory way of describing or measuring microroughness so that we have to depend on defining surface polish by the size of the abrasive used to produce it. In terms of abrasive size, the critical polish (above which friction is independent of it) is about 40 microns.

A major unexplored area is that of the relation between friction and aggregate particle shape and particularly the shape changes which the particles undergo as they wear.

Once we understand how traffic exposure changes pavement skid resistance we can postulate what reconditioning methods must accomplish. It is conceivable that aggregates which tend to polish to unacceptable skid-resistance levels might still make surface courses which are acceptable from the economical as well as the safety standpoint, provided low-cost reconditioning methods can be developed.

## ALLOCATION OF IMPROVEMENT POTENTIAL

Of course, the entire burden of providing traffic with adequate friction does not fall on the pavement alone. Tire design can be improved to give better frictional performance by minimizing tread movement, by making the pressure distribution in the contact area more uniform, by tread design, and by choosing rubber compounds which maximize the adhesion and the hysteresis components of friction on all surfaces. Vehicle design enters the problem via suspension geometry and the vibrational characteristics of the entire vehicle. Similarly, steering geometry and the cornering characteristics of the vehicle influence available and necessary friction.

In the light of the present potential for technological progress in tires and vehicle design, it appears that pavement surfaces can make a greater contribution to an increase in tire-pavement friction. Surface courses which retain high skid resistance over long periods of time are now being laid down in various portions of the United States. In the last analysis this is a matter of using a good aggregate with the correct particle-size gradation.

When desirable materials have to be transported to the construction site over long distances and reconditioning methods are not available, periodic resurfacing may still be the most economical long-range solution. It is, however, important that a state have an inventory of its accessible supplies of skid-resistant materials. If the supply is limited, steps should be taken to prevent its use for purposes other than surface courses.

## CONCLUSION

I hope I have been able to highlight the most important aspects of the pavement slipperiness problem and to show how far our knowledge has progressed. Much remains to be done before we can derive reliable design procedures for surface courses which are optimum in performance, life and cost. To this end we must fully understand the mechanisms of rubber friction, of the tire-pavement contact, and of the polishing process. This is no small task and contributions from many sources will be needed to accomplish it.

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