NATURE AND COMPONENTS OF TYRE-ROAD FRICTION ON WET ROADS

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RINGKASAN

Bila sebuah jalan manjadi basah, kemampuannya untuk menyediakan tahanan gelincir menjadi sangat berkurang. Untuk keselamatan berkendaraan dalam kondisi basah, harus ada suatu tingkatan friksi minimum yang diperlukan antara roda kendaraan dan permukaan jalan. Pengetahuan tentang ketersediaan friksi tersebut dengan demikian diperlukan. Makalah ini mengetengahkan kondisi alami atau mekanisme dari friksi antara roda dan permukaan jalan, serta uraian tentang komponen dari friksi tersebut yang bisa mempengaruhi atau memberikan kontribusi terhadap besarnya tahanan gelincir pada jalan basah.

SUMMARY

When a road surface becomes wet, its ability to provide friction is greatly reduced. For safe driving under wet conditions, a minimum level of the friction between the tyre and the road surface must exist. A knowledge of the availability of this friction is therefore necessary. This paper presents the nature or mechanism of a tyre-road friction, and the decsriptions of components of tyre-road friction which may affect or have a contribution to the magnitude of friction on wet roads.

I. INTRODUCTION

The handling of a maneuvering vehicle (such as cornering, braking/accelerating, or combination of two) will depend upon the available frictional force between its tyres and the road surface. Frictional forces are highest on dry roads where coefficient of friction of 0.7 to 1.0 are usual [Allbert and Walker (1965-66)]. If the water or any lubricants, which act as medium or low tangential shear, wetted the road surface, the friction available will be drastically reduced.

II. MECHANISM OF FRICTION DEVELOPMENT

The mechanism of friction development of a tyre rolling, sliding or combined rolling/sliding on a wet surface, is commonly described by the concept of 3 zones of contact area [Allbert and Walker (1965-66), Moore (1966), Harris (1968), Keen (1968)]. The term "contact" in this concept is not necessarily associated with the direct contact between tyre and road surface, since part (or even all) of the water covering the road may not be expelled during the time available. In fact, it just indicates the area of road surfaces receiving pressure from the tyre, and thus generate resistance to the tyre movements (see Figure 1).

In the forward region or sinkage zone, the tyre contacts the bulk of water covering the road. The major component of frictional force then is due to the hydrodynamic drag. Gough [1959] also included the hysteresis loss, as a component of frictional force, although there is no direct contact between the tyre and road asperities. In other words, tyre deformation can occur either with dry or lubricated contact. It is believed, however, that the hysteresis friction does not occur if an excess of water exist, in which the rolling or sliding tyre may plane on the water and prevent the rubber flowing over the asperities. Nevertheless, the frictional force developed in this zone is very small in comparison to other zones. When the vehicle velocity increases, the time for expelling the water diminishes, the boundaries of the zones move backwards. Along with increasing velocity, the dynamic pressure generated in the water ($p = 0.5 \rho V^2/g$, where ρ is water density, V is vehicle velocity, and g is gravitation) also increases. If the water pressure exceeds the tyre vertical pressure then the tyre is supported by a layer of water film and the forward zone occupies the whole contact area. This condition is often referred to as hydroplaning.

occur due to the deformation of tyre tread, as it is caused by the indentation of surface texture. Actually, even under dry conditions, there is no such thing as a perfectly dry contact region between tyre and pavements; fine water films contaminate all surfaces when the humidity is non-zero. Therefore, when reference is made to a dry contact, this implies a region in which the fluid film thickness has been reduced to that thickness present on

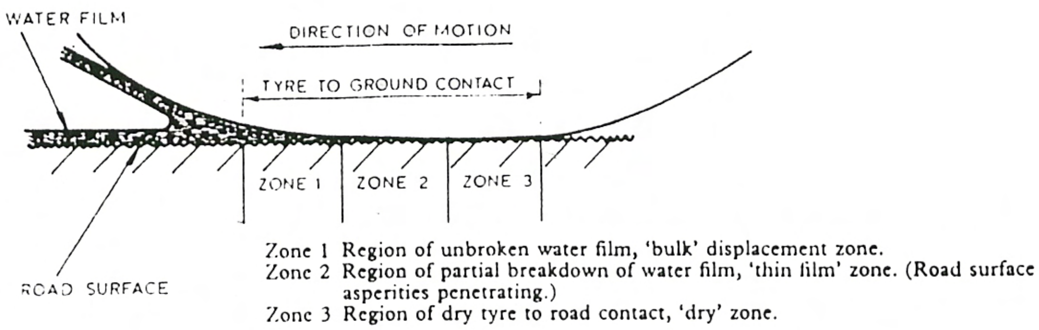

Fig.1. Schematic representation of 3 zone concept. [Allbert and Walker (1965-66)].

In the middle region or transition zone, the tyre proceeds to drape over the larger asperities and make contact with the lesser asperities. The frictional force developed is the drag of partial breakdown of lubricant film, and the hysteresis loss. Due to the squeeze effect, the drag in this zone is greater than in the forward region (although both of them are still very small).The hysteresis loss is built up as more tyre tread envelops the projecting aggregate of the pavement surface. Additionally, it is possible however, that the adhesive friction is also being developed in this zone, as there is dry contact between tyre and road asperities. Clearly, by intimate contact, the molecular interactions between rubber and pavements will lead to adhesive bonds, having high shear strength.

In the rear region, the tread rubber and road surface are in dry contact. The drag of water film is diminished, and replaced by the adhesion, where the surface now is in molecular contact. The hysteresis loss will continue to

what is casually and technically incorrectly termed dry pavement [Browne et.al (1982)]. If the road asperities are sharp, the tearing of ruber is possible, and the friction is increased [Tabor (1959)]. This additional component is commonly referred to as abrading friction. This component, together with other components mentioned above, will be described in detail in the following sections.

III. HYDRODYNAMIC COMPONENT OF FRICTION

The hydrodynamic drag, build up from forward region, can be divided into two components: water drag and viscous drag [Trollope and Wallace (1962)]. The water drag is derived primarily from the impact of the water on the leading edge of tyre.This force is a function of film thickness, water viscosity, and impact speed. Although the pressure developed by impact speed can exceed the tyre vertical pressure (i.e. results in hydroplaning), the contribution (in tangential direction) to resist the tyre longitudinal movements is likely to be of negligible magnitude.

The viscous drag is derived from the viscous resistance of the water which is continously sheared between tyre and pavement. This component can be calculated from Newton's law of viscous shear. Roberts [1971] found that the viscosity of water increased dramatically when the water film thickness was decreased below 500 A° (5x10^{-6} Cm). Hence, the thinner the film thickness, the greater the contribution of viscous drag. Some theoritical calculations, however, showed this friction due viscous shear to be insignificant [Moore (1967), Ludema (1975)].

IV. ADHESIVE FRICTION

The adhesion component of friction is due to the making and breaking of atomic junctions between the rubber and pavement surfaces [Meyer (1968)]. There is general agreement that adhesion has distinct viscoelastic properties. The coefficient of adhesional friction is known to exhibit a peak value at creep speeds in about 1 cm/sec [Ludema and Tabor (1966)]. This peak will shift to a lower speed with decreasing ambient temperature, and to a higher speed with increasing ambient temperature. In practice, therefore, this friction most often decreases as sliding speed increases.

In ideal case, the true area of contact of two atomically smooth surfaces would be equal to the nominal area of contact, and adhesive friction would be very high. However, for the usual surface which is very rough on the atomic scale, contact would be limited to the highest proturbances on the surfaces.

Even though the mechanism of adhesive friction is so far not fully understood, it is well known that on well-lubricated surface the adhesion component may be greatly reduced due to weakening of the shear strength of bond by the water film. As an approximation, a film thickness of just exceeding the molecular dimension (i.e. Angstroms), is probably enough to significantly reduce the direct bonding of tyre rubber to the road material. An experiment by Roberts and Tabor [1968], using the glass surface (moving at a uniform speed on the rubber hemisphere), showed that the friction coefficient decrease sharply from 0.7 to 0.07 by increasing film thickness from 80 A° to 110 A°, and then decrease gradually to 0.048 at the film thickness of 180 A°.

V. HYSTERETIC FRICTION

On a textured surface, when a tyre is sliding or rolling, the tread rubber is subjected to continous deformation by the asperities. The hysteresis force is a function of damping energy loss in deformation (so called deformation loss). The rubber in front of an asperity is compressed when it approaches the asperity and expands when the rubber flows over the asperity. A certain amount of energy is required to compress the rubber element in front the asperity but owing to damping losses only a part of this energy which is stored in the rubber is recovered. The lost energy is converted into heat. The loss caused by damping results in an incomplete recovery of rubber upon expansion, thus creating unsymmetrical pressure distribution shown in Figure 2. The net horizontal component of the pressure force is the hysteresis component which acts in the opposite direction to sliding.

When the textured surface is perfectly lubricated the adhesion component disappears, but hysteresis component always exist as the asperities can deform the rubber surface. The texture of the surface and the damping property of the tread rubber, therefore, will determine the magnitude of hysteresis friction.

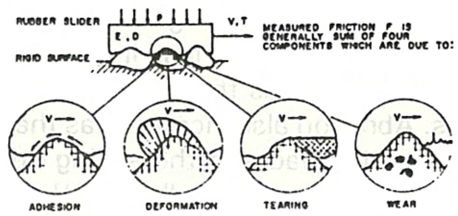

Fig.2. Components of rubber friction. [Kummer (1968)].

In general, the road surface is composed of a number of scales of texture ranging from microscopic sizes to about 3/4 inch. According to Yandell [1974], it is the scales's absolute slope (rather than the scale's size) which has a direct effect to the hysteresis friction. The coefficient of hysteresis friction is the sum of the coefficients generated on each scale. The size of scale, however, will influence the masking effect of surface lubricant films, and the sliding speed of peak friction.

The damping properties of the rubber is the most important one for the hysteresis friction, beside other characteristics: resilience, hardness, and elasticity. The increase in hysteretic friction due to the higher damping properties of the rubber, is well established by the fact that tyres made of synthetic rubber provide higher skid resistance than that given by their natural counterparts [Maycock (1965-66), Savkoor (1966)].

VI. ABRADING FRICTION

This component of friction is contributed by the fine scale texture with sharp angular projections on the hard (stone) surfaces. The sharp asperities tear or wear particles from the rubber. According to Schallamach [1954], this process is due to tensile failure, induced by stress concentration in the rubber surface behind the track asperities. It seems, however, that the heating of rubber (such as on braking or cornering) also participates in develop this process. The force exerted on the tyre tread rubber to abrade it is the measure of this friction.

It was found experimentally by Yandell and Gopalan [1976] that the finer scales of texture are responsible for greater amount of abrasion but participate less in generation of hysteresis friction as the speed of sliding increases. Abrasion also increases as the damping factor, the load and the sliding speed of the rubber increase [Yandell (1971)]. On well-lubricated surfaces, however, the abrading friction, similar to the adhesive friction, is believed to be insignificant. Likewise, it could be argued that the abrading components of friction might have already been accounted for under one of the other components of friction [Ludema (1975)].

VII. CONCLUSIONS

1. The mechanism of tyre friction development on wet roads has been describe by the concept of 3 zones of contact area. With increasing vehicle speed the boundaries of the zones move backwards, results in decreasing frictional force. The condition becomes hydroplaning if the forward zone occupy the whole contact area.
2. The frictional force developed in the forward (or sinkage) zone is very small in comparison to other zones. The main component in the forward zone is the hydrodynamic friction.
3. In the middle (or transition) zone, the frictional force developed is greater than in the forward zone, although its magnitude is still very small. The hydrodynamic, adhesive, and hysteretic frictions are the possible component in this zone.
4. The rear (or dry) zone is the main source for the frictional force developed between a tyre and road surface. The main components in this zone are adhesion and hysteretic friction. In addition, the abrading friction may occur if the road asperities are sharp.
5. In terms of significance, the hysteretic friction is the most significant, whereas the hydrodynamic friction being the least (with an exceptional for hyroplaning case). The adhesive friction, on the other hand, has a peak value at speed of 1 cm/sec (which is much lower than the normal vehicle speed), whereas the abrading friction might have already been accounted under one of the other components of friction. On well-lubricated surface, however, the adhesive and abrading components are believed to be insignificant.

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