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A Study of the Effect of the Wheel Load, Tire Dimensions and Water Depth on the Vehicle Critical Speed in Wet Roads

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Abstract

A study of the critical speed of the vehicles on the wet roads has been done. And how it is affected by the following parameters: wheel load , tire width, tire radius and water layer depth and also the nature of the contact area of the tire (grooved or smooth).

It was found that the wheel load increase the critical speed positively while the tire width, the tire radius and the water layer depth decreased the critical speed, It was also found that grooves in the tire surface improve vehicle performance on wet roads .

Kay Word: Critical speed of the vehicle, Road parameters ,Tire parameters

دراسة تأثير حمل العجلة وأبعاد الإطار وعمق الماء على السرعة الحرجة للمركبات في الطرق المبللة

الخلاصة

هذا البحث يتناول دراسة السرعة الحرجة للمركبات على الطرق المبتلة والعوامل التي تؤثر عليها. هذه العوامل هي حمل العجلة ، عرض الإطار، نصف قطر الإطار، وعمق طبقة الماء على سطح الطريق وذلك في حالتي استخدام إطار (أملس أو ذو أخاديد).

من هذه الدراسة وجد إن تأثير حمل العجلة على مقدار السرعة الحرجة ايجابي (يزيدها) بينما وجد إن تأثير عرض ونصف قطر الإطار وعمق الماء على السرعة الحرجة هو سلبي (ينقصها) . كذلك وجد إن الأخاديد تُحسن أداء قيادة المركبة على الطرق المبتلة.

الكلمات الدالة: السرعة الحرجة للمركبات، عوامل الطريق، عوامل الاطار

Introduction

Hydroplaning is a major safety concern in wet-weather driving which occurs when the traveling speed of a vehicle becomes so high that the hydrodynamic pressure of the water between its tires and the pavement surface rises to a critical value. When this condition prevails, the tires would be supported by the water film and the driver may lose the braking and the steering control of the vehicle [1].

Statistics studies that cover various parts of the world indicate that is approximately 20% of all the road traffic accidents occur due to wet weather conditions[2,3]. Although there are no detailed statistics on the exact causes of the wet-weather accidents, it is believed that low skid resistance and hydroplaning are major factors leading to the accidents[1,4,5]. Hydroplaning refers to a situation in which the presence of water film in the tire-and-pavement contact region significantly reduces the frictional resistance at the interface, and this results losing of the skid resistance and vehicle steering control.

On the road surface with a known thickness of the water film, the factors that influence the vehicle hydroplaning or critical speed (i.e. vehicle speed at which the hydroplaning occurs) including the tire related factors and the pavement related factors. The main tire related factors are the tire inflation pressure, the wheel load, the tread depth and the tire type. For instance, increasing the tire inflation pressure, the wheel load or the tire tread depth will raise the critical speed. Hence reducing the hydroplaning risk [3,6].

The main pavement related factors affect the hydroplaning or critical speed are: surface micro texture, macro texture nature and the pavement cross-slope. Increasing the pavement cross-slope facilitates drainage, resulting a thinner water film thickness on the pavement surface and higher hydroplaning or critical speed [7].

The Pavement Parameters Used In This Study

The parameters adopted in the analytical hydroplaning that used in this study model are presented in this section.

Pavement Surface Model

The pavement surface model used in this study is that adopted in refs [1,8,9,10,11] . This model considers a smooth plane pavement surface for all the analysis and this represent the worst case and a conservative estimation of the critical speed for in-service pavements , and this is presented in table (1).

Water Film Properties

The properties of the water film that covers the road (at 20^{o}C temperature) used in this study are: The density, dynamic viscosity and kinematic viscosity of water are 998.2 kg/m, 1.002x 10^{-3} Ns/m^2 and 1.004 x10^{-6}m^2/s respectively [12].

Analytical Approach

Reynolds equation has been used to analyse the parameters and asses the performance of the operation. The contact region between the tire and the road (fig.(1)) looks like the convergence half of the conventional bearing. Therefore Reynolds equation of convergence and squeezing terms in the right hand side has been used this from is[13]:

$$\frac{\partial}{\partial x}\left(\frac{h^3}{\mu}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{\mu}\frac{\partial P}{\partial z}\right)=6U_{\circ}\left[\frac{\partial h}{\partial x}\right]+12\frac{\partial h}{\partial t} \quad \ldots(1)$$

Assuming that $\frac{\partial h}{\partial z}=0$. And considering the viscosity is constant over the whole contact region ,then expanding Reynolds equation to give:

$$h^3\frac{\partial^2 P}{\partial x^2}+3h^2\frac{\partial h}{\partial x}\frac{\partial P}{\partial x}+h^3\frac{\partial^2 P}{\partial z^2}=6U_{\circ}\mu\frac{\partial h}{\partial x}+12\mu\frac{\partial h}{\partial t} \quad \ldots(2)$$

Reynolds equation has been solved numerically using the finite difference technique. And this was achieved by dividing the contact region into (m) number of grids annually and (n) number of grids axially as shown in fig (1). A reasonable accuracy was achieved in the implementation of the computer program that based on the finite difference model. This was achieved by using (m x n) equal (48 x 128).

Modeling equation (2) by using the finite difference technique of five nodes scheme gives:

$$D_1P_{i+1,j}+D_2P_{i-1,j}-D_3P_{i,j}+D_4P_{i,j+1}+D_5P_{i,j-1}=D_6 \quad \ldots(3)$$

Solving equation (3) using the iteration technique gives the water film pressure at all the points in the annual and axial directions in the contact region. And this was achieved by using the matrix method Gaussian elimination [14] (by the computer program) in solving the simultaneous equations, which represent all the nodes.

Results And Discussion

The program results were obtained and the performance characteristics were monitored by drawing the following relationships.

The pressure variation annually is presented in fig (2) . This figure shows the same behavior of the oil film pressure on the bearing application. Noting that in this application the pressure profile has a sharp raise to give the peak . And this is due to the nature of the tire geometry.

Fig (3) shows the water film pressure variation axially. The pressure profile is chopped into many portions depending on the number of the annual grooves. Any way this technique (using the annual grooves) helps in raising the critical speed of the vehicle, so this type of tires usually are used over the raining seasons. While the smooth surface tire has a uniform pressure profile, and this gives a lower critical speed, therefore it is imp referable to be used over the raining seasons.

The Effect Of The Tire Width

Figure (4) shows the relationship between the critical speed of the vehicle and the tire width for two types of tires. these types are, 1st, with annual grooves and the 2nd is for smooth surface tire. Generally, it is clear from the figure that the tire width effects the critical speed of the vehicle adversely for both types of tires. And this means that the narrow tires is safer than the one with a large width to be used in the wet roads, and this is well justified on the bases of the pressure, area and force relation. Also this figure shows that using the tire annually grooved is safer than that of smooth surface. This is because that the groove drain the water and break the water film pressure and thus preventing build up high pressure in the water film, which lift the tire and losing the vehicle control**.**

The Effect Of The Tire Radius

The relation between the critical speed of the vehicle and the tire radius for smooth and grooved tires are presented on figure (5). Generally, the tire radius effect the vehicle critical speed adversely (as the tire width effect). And this due to the fact that; as the radius increased as the surface flat end and thus the contact area increased which result higher force, and that lift the tire early. Also this figure shows that the grooves improve the vehicle tire performance by increasing the critical speed and make the driving on a wet roads safer . This is due to draining the water and breaking the pressure profile.

The Effect Of The Wheel Load

Figure (6) shows the relationship between the vehicle critical speed and the wheel load, for both smooth and grooved tires. This figure shows that increasing the wheel load has a positive effect on the critical speed, i.e. increasing it. And this is due to requiring a larger lifting force, and this require a higher water film pressure, and this couldn't be achieved at low vehicle speed. Also from this figure, it is clear that the tire grooves improve the operation performance (increasing the critical speed) because it help in draining the water and breaking the pressure profile, and this have the same behavior and trends of ref [15] figures (4.12)(4.15).

The Effect Of The Water Layer Thickness

Figure (7) shows the relationship between the critical speed of the vehicle and the depth of the water layer on the road, for smooth and grooved tires. From this figure it is clear, that, generally, increasing the depth of the water layer decreasing the critical speed. And this due to increasing the contact area between the tire and the water. And also it could be seen that the effect of the water lay**e**r depth , from small values of depth is much higher than that of the large values of the water depth. And this is well justified on the bases of the convergence zone shape, which has little effect when the water film thickness becomes large. Also it could be noticed that the effect of the grooves, for small values of water layer, depth is larger than its effect on the case of large value of water layer depth. This is due to the blockage of the water passage by the water. But another adverse factor could raise and may need to be considered carefully. This factor is the water wedges which has a great effect in the case of large value of water layer depth.

Conclusions

From the results of this study, the following conclusions may be drawn.

1- The heavy vehicle performance is safer than the light vehicle in the wet roads.

2- Increasing the width, the radius or both has adverse effect on the vehicles performance in the wet roads.

3- A road with large value of water depth is more risky than that of small values of water layer depth.

4- Using the grooved tires , especially with random shapes almost overcome the wet road problems**.**

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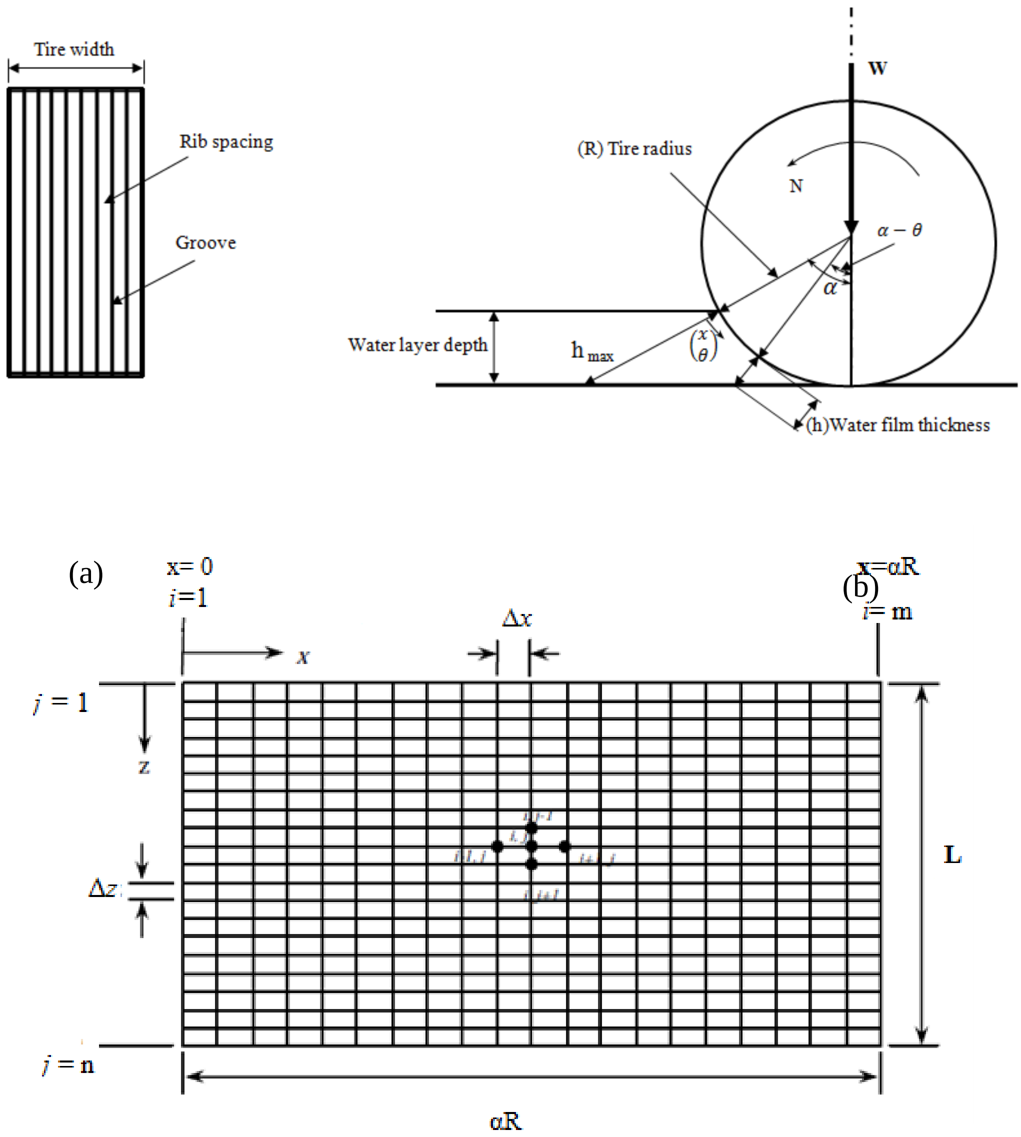

(c)

Fig. (1) (a) Tire geometry, (b) contact region shape , (c) contact region divided into annual and axial grids

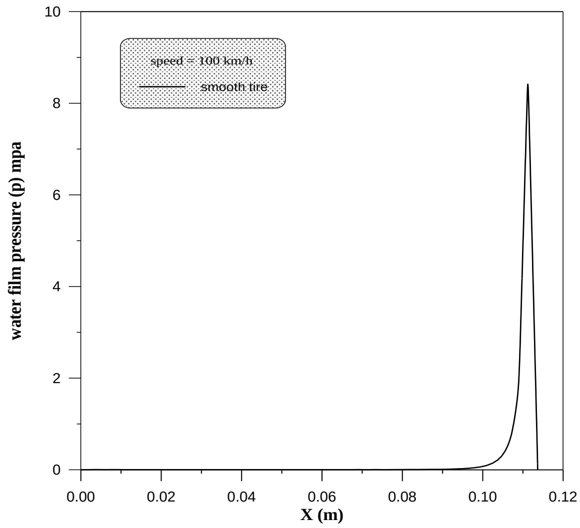

Fig. (2) The water film pressure (*P*) variation annually

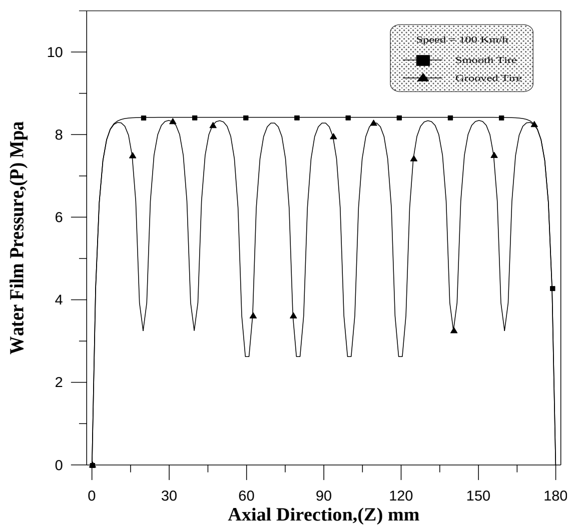

Fig. (3) The water film pressure (*P*) variation axially

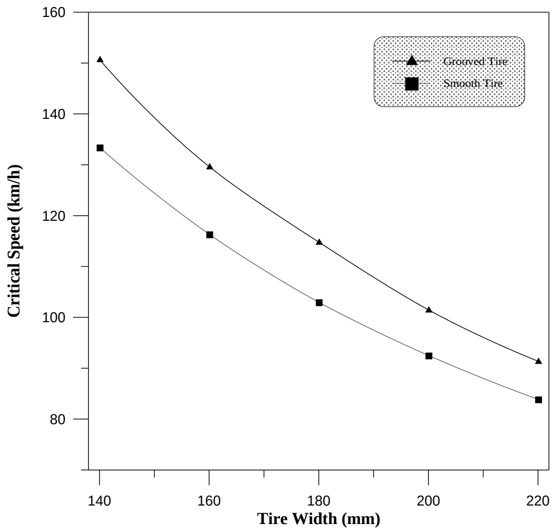

Fig. (4) Critical Speed Variation With The Tire Width

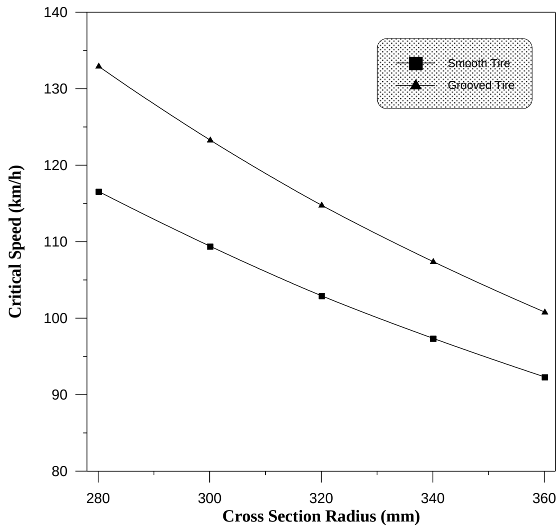

Fig. (5) Critical Speed Variation With the Cross Sectional Radius

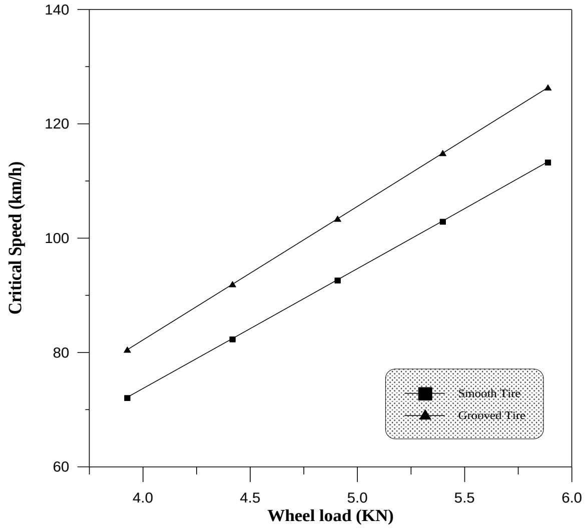

Fig. (6) Critical Speed Variation With wheel load

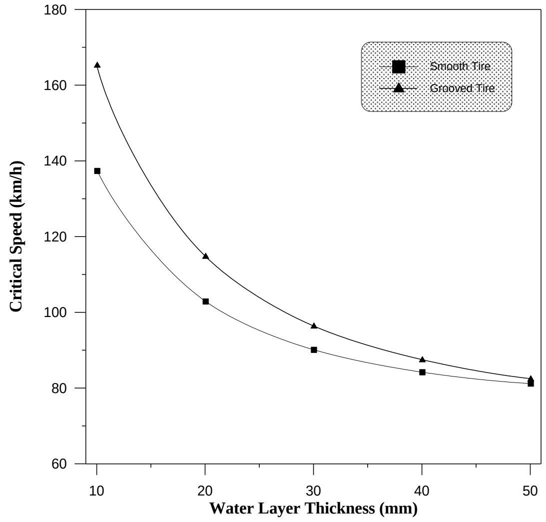

Fig. (7) Critical Speed Variation With The water Layer Thickness

Table (1): Parameters used in the analysis

Parameter	Details
Passenger car tire	ASTM E 501 standard G78-15 tire
Tire analyzed	Smooth tire, Longitudinally grooved tire
Pavement surface	Smooth plane surface
Wheel load	3.924 , 4.4145 , 4.905 , 5.3955 and 5.886 KN
Cross Section Radius	280 , 300 , 320 , 340 and 360 mm
Tire width	140 , 160 , 180 , 200 and 220 mm
Tire groove width	8 mm
Tire groove depth	8 mm
Center-to-center spacing	20 mm
Water depth	10 , 20 , 30 , 40 and 50 mm