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A3 6 Hot Wheels: A study into extreme tyre degradation

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Abstract

The authors of this paper sought to investigate the reality behind the popular franchise "Hot Wheels" and if it is possible to cause a car's tyres to catch fire purely from high speeds. We found that auto-ignition should be reached at 315 °C but the required velocity was heavily dependent on vehicle's mass. An average motor vehicle of 1600kg was found to have its' tyres catch fire at 1570 kph provided regular linear travel or a slightly more reliable and achievable value at 1210 kph if the tyres became fully locked. The implications of this were then explored for safety purposes in high speed vehicles, stating a minimum safe braking distance for an average car weight at these extreme speeds of 6.38 km.

Introduction

Tyre behavior is an extremely important topic to be studied as the majority of travel in the world revolves around it. This paper highlights some of the general properties of car tyres that can be expanded upon in future research while having a specific focus on the upper limit of tyre life.

For an average tyre, auto-ignition can occur without external stimulus at 315 °C [1]. Therefore to heat a tyre to its ignition threshold, the amount of energy required must be found.

Theory

We can assume the lower temperature of road tyres to be around room temperature ∼ 25.0 °C when they are not in use. Therefore we take ΔT required from heating to be 290 °C.

This temperature increase is a result of frictional forces acting on the tyre and being absorbed in the form of heat instead of kinetic energy or sound. This can be expressed as work done, Q, by friction and then written more specifically as a function of its' base components with frictional coefficient μ and normal force Mg.

$$Q = F_{\text{friction}} \cdot d, \tag{1}$$

$$Q = \mu \cdot \frac{M_{\text{car}}}{4} \cdot g \cdot v \cdot t, \tag{2}$$

The above represents the energy available to be transferred to the tyres via frictional forces, while the energy required to raise the temperature of the rubber is governed by the equation below stating heat capacity c of tyre tread, found at ∼ 1.48 J/gK [2].

$$Q = M_{\text{tyre}} \cdot c \cdot \Delta T, \tag{3}$$

Equations (2) and (3) can now be equated and rearranged to find the threshold velocity for a car's tyres to catch fire. It should be noted there are a number of variables that cause the results to vary, however on the basis of averages in line with comparative studies, we take M_{tyre} as 10 kg and M_{car} as 1,600 kg [3]. Heating is applied significantly easier in lower mass tyres, however for a standard road tyre of reasonable mass, a time t is selected as 5 seconds since it is a realistic length but allows heating to be applied more rapidly to minimise cooling affects due to heat convection over time.

$$v = \frac{4 \cdot M_{\text{tyre}} \cdot c \cdot \Delta T}{M_{\text{car}} \cdot \mu \cdot g \cdot t}, \tag{4}$$

Results

We will look at two different scenarios, first when the tyres are rolling freely. Here, the force acting upon the car is that of rolling resistance and is non linear as at higher speeds, the tyres partially slide. The coefficient of resistance can be found from the model below [4], with coefficients from these works of 10^{-2}, $5 \cdot 10^{-7}$ and $2 \cdot 10^{-7}$ for f_0, f_{01} and f_{02} respectively and velocity, v in units of kph.

$$\mu_{\text{rolling}} = f_0 + f_{01} \cdot v + f_{02} \cdot v^2, \tag{5}$$

By numerically equating equations (4) and (5) we can see that a threshold velocity for ignition is reached when $\mu = \sim 0.50$ and simultaneously resistance only reaches that value when at speeds of ~ 1570 kph.

This can be compared to a similar scenario in which excessive brake pressure causes the tyres to fully lock, now creating a situation where the tyres do not rotate at all and frictional forces are entirely sliding rather than rolling. Therefore taking the coefficient of sliding friction between rubber and asphalt as ~ 0.65 [5], we find that the speed required is ~ 1210 kph.

These results provide important safety information regarding the limits of high speed vehicle travel on standard tyres due to differences between auto-ignition thresholds for a rolling vs a fully locked scenario. There is a window in vehicle velocity in which the car can function without issue but if the tyres were to lock up, they would catch fire. This happens when the brakes apply more force than the maximum available traction, which is as defined as below with μ representing the coefficient of static friction, m being mass and g as acceleration due to gravity.

$$F_{\max} = \mu \cdot m \cdot g, \tag{6}$$

As the breaking distance is equal to the kinetic energy of the system divided by force applied, we can rearrange and cancel variables to find an equation for minimum breaking distance without locking the breaks and relating to velocity v.

$$d = \frac{v^2}{2 \cdot \mu \cdot g}, \tag{7}$$

Using μ of 0.90 [5] representing the maximum grip available, once a velocity of 1210 kph has been exceeded, the minimum distance in which the car can safely come to a stop is 6.38 km.

Conclusion

By comparing frictional coefficients at both rolling and sliding scenarios we find there is a "danger velocity" past which a lockup would result in the tyres igniting. An average vehicle has this threshold of ignition at 1210 kph if the tyres locked and an upper limit, at which it will ignite during regular travel, of 1570 kph. To avoid lockups when past the lower threshold, brake force must not exceed the maximum available traction. Therefore we found an average safe brake distance of 6.38 km.

References

[1] `https://www.michelin.co.uk/tyre-fire-hazards` [accessed 04/11/24]

[2] Liu, Shuo, Liu. *et al.*. (2023). `http://dx.doi.org/10.3390/lubricants11090402`.

[3] Yu, Z., Hou, X., Leng, B. *et al.* (2022). https://doi.org/10.1007/s43684-022-00020-8

[4] M. Untaru et al, Dinamica Autovehiculelor pe Roti, Editura Didactica si Pedagogica, Bucuresti, (1981)

[5] `https://www.engineeringtoolbox.com/friction-coefficients-d_778.html` [accessed 024/11/24]