FOOTPRINT ANALYSIS OF RADIAL PASSENGER TIRE

Radyal Otomobil Lastiğinin Taban İz Analizi

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ÖZET
Bu çalışmanın amacı 195/60R15 ebatlı olan otomobil lastiğinin yere basma alanının değişik lastik hava basınçları altında analiz edilmesidir. Çalışmalar iki kısma ayrılmıştır. İlk olarak deneySEL çalışma yapılmıştır. DeneySEL çalışmada lastiğin üzerine gelen yük sabit tutulmuş ve hava basınçları değiştirilerek lastiğin yere basan toplam alanı ve bir mm üzerine düşen yük hesaplanmıştır. İkinci olarak, ANSYS programı kullanarak yapılmuştur. Lastiğin ANSYS programı ile çizimleri yapılmış ve malzeme özellikleri tahmini olarak tanımlanmıştır. Sabit yük ve değişik basınçlar altında lastik simule edilerek deneySEL sonuçlarla karşılaştırılmıştır.

Anahtar Kelimeler: Otomobil tekeri, Taban izi, Kontak yüzey, ANSYS.

ABSTRACT
The aim of this study is to investigate the details of foot print analysis of 195/65R15 passenger tire. The study consists of two parts: First, an experimental study was conducted. Total contact area was calculated under the stable load and different inflation pressures and also the load calculated for per mm in the experimental study. Second, ANSYS simulation method was used to model the footprint of the tire. Tire components were drawn by ANSYS and physical properties and conditions were loaded to the program. Finally, ANSYS solution and experimental results were compared with each other.

Keywords: Car tire, Footprint, Contact Area, ANSYS.

Introduction
Tyres are used on many types of vehicles, such As bicycles, motorcycles, cars, trucks, earthmovers, and aircraft. Tires enable better vehicle performance by providing traction, braking, steering, and load support. Tires form a flexible cushion between the vehicle and the road, which smooths out shock and makes for a comfortable ride.

Tyre as one of the most important components of vehicles requires to fulfill a fundamental set of functions as follows.
- Provide load-carrying capacity
- Provide cushioning and dampening
- Transmit driving and braking torque
- Provide cornering force
- Provide dimensional stability

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Various parts of a typical modern radial tyres used in passenger cars. The mechanical properties of a tyre describe the tyre's characteristics in response to the application of load, torque, and steering input, resulting in the generation of external forces and deflection. Such mechanical properties are interrelated, and thus a design decision affecting one factor will influence the other factors, either positively or negatively.

Knowledge of how the tyre operates can give engineers insight into design considerations. In order to achieve these tasks many investigators have tried during the past three decades to develop robust mathematical models and simulation schemes for the description of kinematics and dynamics of the rolling of pneumatic tyres on rigid and non-rigid surfaces.

Inflation pressure distribution is directly affected the footprint (contact patch) of the tire. Contact patch is the portion of a vehicle's tire that is in actual contact with the road surface. The contact patch is the only connection between the road and the vehicle.

The size and shape of the contact patch as well as the pressure distribution within the contact patch are important to the ride qualities and handling characteristics of a vehicle. Since the wear characteristics of tires is a highly competitive area between tire manufacturers, a lot of the research done concerning the contact patch is considered highly proprietary and, therefore, very little is published on the subject.

Material and Method

The contact patch, or footprint, of the tire, is merely the area of the tread which is in contact with the road surface. This is the area which transmits forces between the tire and the road via friction. The length-to-width ratio of the contact patch will affect steering and cornering behavior.

The shape of a tire's contact patch or "footprint" greatly influences its performance and is dependent on its profile or "aspect ratio". Low profile tires (most performance tires) have a short and wide contact patch that is effective in converting the driver's input into very responsive handling, cornering stability and traction (especially on dry roads).

High profile tires (light truck and most passenger tires) have a long and narrow contact patch which helps to provide predictable handling, a smooth ride and especially good traction in snow.
If tire pressure is too high, the tire contact patch is reduced. This decreases rolling resistance, but does not necessarily decrease braking distance. In addition, ride comfort is reduced and the center of the tread may wear more quickly than the shoulder.

If tire pressure is too low, the tire contact patch is increased. This increases rolling resistance, tire flexing, and friction between the road and tire.

Underinflation can lead to tire overheating, premature tread wear, and tread separation in severe cases. Significant underinflation can also increase braking distance.

The vehicle whose tire is analyzed in this study is Toyota Corolla. The load of the vehicle affects the footprint area and therefore the tire was kept under a constant load and its pressure was changed to determine the effect of pressure change on footprint areas. The load have to be measured flat ground because of equal load distribution therefore the measurement realized on the loading area of the car.

Total load of the car is 1230 kg. Foot print analysis was performed on the front left tire. Therefore front left tire load was measured by load-cell. Load cell sensibility is 10 kg and the total load of the tire is 350 Kg. = 3433.5 N.
A tire footprint analysis was implemented in the ANSYS™ finite element model through tire-road contact analysis as shown in Figure 3. Contact problems are highly nonlinear and require significant computer resources to solve. Due to the symmetry of the problem, only a quarter model is analyzed and we used symmetric boundary conditions to decrease the calculation time as shown in Figure 4. In the FE model surface-surface (CONTA174-TARGE170) and flexible-rigid contact was established using ANSYS™ Contact Manager as shown in Figure 5.

Figure 3. 195/65R15 Type tire

Figure 4. Finite element model in ANSYS.

Figure 5. Tire-road contact problem sketch contact surfaces and surface normals to each other
Road conditions were modeled as a rigid target surface. Because of
tightness, target surface is not required any other dimensions like height or
thickness. Due to the symmetry of the problem, only a quarter road model is
analyzed as shown in Figure 4. Note that to create a rigid-flexible model, you have
to mesh only those parts of the model which will be used as flexible contact
surfaces (do not mesh the rigid target surface) before launching the Contact
Manager wizard. For this problem we used the TARGE170 element to model the
road conditions.

The stress-strain behavior of rubbers is elastic (i.e. recoverable) but highly
nonlinear. This type of material behavior is known as hyperelasticity. Two different
forms of strain energy potentials available are: a polynomial model (of which the
Mooney-Rivlin is a particular case) and the Ogden model. The tire material was
modeled as a nonlinear elastic material using Mooney-Rivlin Rubber model. It is
nearly identical to the 2-parameter existing ANSYS Mooney-Rivlin model. The
strain energy density function is defined in terms of input parameters
\( C_{10} \) and \( C_{01} \).

\[ C_{10} \text{ and } C_{01} \text{ are material constants and they are shown in Table 1.} \]

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\begin{array}{|c|c|}
\hline
\text{Material Properties} & \text{Mooney-Rivlin Constants} \\
\text{\( E = 2.82 \) MPa} & \text{\( C_{10} = 0.293 \) MPa} \\
\text{\( \nu = 0.49967 \)} & \text{\( C_{01} = 0.177 \) MPa} \\
\hline
\end{array}
\]

Table 1. Material properties and Mooney-Rivlin constants for tread
compounds.

For this problem we used the CONTA174 (Contact, 8 nd surf 174) element
due to the compatibility with 3D model.

The element has three degrees of freedom at each node: translations in the
nodal x, y and z directions. Contact occurs when the contact node penetrates the
target surface. The tyre model was subjected to loading in two sequential steps.
The initial loading was caused by the tyre inflation pressure, which was assumed to
be uniform within the tyre.

The inflated static tyre is then subjected to normal loading through the
application of a specified normal deflection of the tyre at the contact region. Tested
vehicle has had 3433.5 N weight.

Normal loadings have taken into account as a vehicle weight. In the finite
element models, pressure values that are used in the experimental study are used
to simulate the inflation pressures.
Result and Discussion

Tire footprints were generally analyzed manually. In this method, the car was lifted by car lifter and a paper was put on the flat ground. Maximum Inflation pressure (60 psi) was pumped into the tire and ink was applied to the tire surface. Then tire was put down to the paper and waited for 30 seconds. After that tire is lifted and paper ids drawn away. The applications were conducted for different inflation pressures and received experimental footprints.

Figure 6. Foot print area measurements using experimental method.

Experimental results show that, tire footprint areas changes depends on inflation pressure. If tire has over inflation pressure, foot print areas decrease. For this reason load increases on the contact area and therefore rapid worn-out and handling problems occur in a short time.

Figure 7. Ansys model results for 11 psi pressure (left) and 14 psi pressure (right).

The numerical foot print analysis also show that footprint areas increase with under inflation and decrease with over inflation pressure.
Figure 8 compares the experimental and numerical results. The experimental and numerical footprint analysis show that footprint areas increase with under inflation and decrease with over inflation pressure.

**Conclusion**

Experimental results show that, tire footprint area change depends on inflation pressure. If tire has over inflation pressure, foot print areas decrease. For this reason, load is increasing on the contact area and therefore rapid worn-out and handling problems occur in a short time.

The numerical foot print analysis show that footprint areas are increasing under inflation and decreasing over inflation pressure. The recommended inflation pressure is 32 psi for the size of tire investigated in this study. The results show that inflation pressure between 30 and 42 psi has similar values. Therefore this range of inflation pressures is applicable for this tire.

A study was made of the relationship between tire inflation pressure and tire contact pressure. Various passenger tires were tested in the laboratory under various combinations of load and inflation pressures; the corresponding average contact pressures were determined by the "dirty print" approach.

It was found that under normal conditions of wheel load and inflation pressure the average contact pressure between the tire and the road will be less than the tire inflation pressure tire contact pressure is a function of both inflation pressure and wheel load and is a constant depending on the type of tire; and the relationship between tire inflation pressure and contact pressure lies within a narrow band for the tires tested; for the combination of wheel load and tire pressures recommended by the manufacturers.
References


