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Relationship between wear and mechanical properties of tread rubbers

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ABSTRACT

The mechanical properties of tread rubbers for off-road pneumatic tires used in road construction and mining machines are analyzed in the paper. The main dependencies that establish the relationship between the wear intensity and the complex mechanical properties of tread rubbers are presented. The effect of external factors on pneumatic tire wear is analyzed. This ultimately determines the tire service life and the reliability of machines during operation.

Keywords: tread rubber, tire, wear intensity, friction, mechanical properties.

1. INTRODUCTION

The durability of pneumatic tires used in road construction and mining machines is determined by the service life until the tread pattern wears out beyond acceptable limits, or until it fails due to the rupture in the carcass and tread delamination.

Rubber wear is a complex process, primarily because it depends on the combination of conditions that cause it. Wear (abrasion) is the process of changing the mass or size of rubber as a result of wear under laboratory or operational conditions [1–3]. Wear intensity is the reduction in mass, volume or thickness of the worn layer for tread rubber per time unit.

The wear is a more complex process by its physical nature than external friction, and is the result of the combined effects of physical-chemical and mechanical processes occurring in the surface layer of contacting bodies.

2. MECHANICAL PROPERTIES OF RUBBERS

The relationship between wear and the complex mechanical properties of rubbers is quite narrow and special [4, 5]. The equation is as follows, relating the wear intensity to the dynamic module and strength properties for tread rubbers based on butyl caoutchouc

$$J = k \cdot \frac{E_D \cdot F'}{N_Z}, \tag{1}$$

where E_D – dynamic module determined at 10 % tensile strain and 16 Hz frequency; F' – friction force; N_Z – rupture energy; k – proportionality constant.

Experimental tests confirmed the validity of equation (1) on Dunlop-Lambourne machine at the constant value of the friction force [4]. It has been shown that it is possible to decrease E_D / N_Z by increasing the molecular weight, decreasing the butyl caoutchouc unsaturation, changing the sulfur content, and introducing a plasticizer. This will lead to increased rubber wear resistance. The results of rubber laboratory tests were confirmed by data from road tests of pneumatic tires in Texas (USA).

The relationship between rubber durability and two main properties (strength, hysteresis) we described by the equation

$$\beta = k_1 \cdot W_Z + k_2 \cdot H_0, \tag{2}$$

where W_Z – rubber strength; H_0 – relative hysteresis; k_1, k_2 – constants.

Table 1: Mechanical properties of modern tread rubbers for off-road pneumatic tires

Parameter	Values for rubbers on based caoutchouc *		
	NC	PI + PB	PI + PB + BSC
Stress at 300 % elongation f_{300}, MN/m^2	125…180	90…140	90…130
Tensile strength f_Z, MN/m^2	260…310	190…230	180…220
Relative elongation ε, %	400…550	450…550	450…220
Tear resistance f_P, kN/m	100…125	80…95	75…85
Hardness by TM 2, conv. units	60…67	60…64	60…65
Elasticity E, %	46…56	44…47	41…45
Hysteresis losses in the energy cycle mode k/E_D	0,23…0,32	—	—
Strength by crack under bend, kc	140…200	20…120	10…50
Brittleness temperature by ISO, ºC	–58	–69	–67
Abrasion on the device α, m^3/TJ (cm^3/kW·h)	82…109 (300…400)	60…76 (220…280)	60…67 (220…280)

* NC – natural caoutchouc; PI – isoprene; PB – butadiene; BSC – styrene butadiene caoutchouc.

Having summarized the abrasion data of rubber different compositions (Table 1), it is proposed to use the next equation

$$J = k \cdot \frac{\mu \cdot H_0 \cdot N}{f_Z} \cdot \tag{3}$$

We will write down the dependence of the rubber wear intensity on their properties, obtained using the mathematical statistics methods [1, 6] from open information references

$$J = A - B \cdot H - C \cdot f_Z, \tag{4}$$

where H – Shore hardness; A, B, C – constants.

A similar dependence was established for relative wear of tread rubbers based on road test data.

The generalized dependence for the wear intensity of tread rubbers from different compositions is presented in the form, obtained using the variation statistics methods

$$J = \frac{k}{f_Z \cdot f_{300} \cdot \sqrt{\Theta}}, \quad (5)$$

where k – factor by on the caoutchouc type ($k = 3 \cdot 10^7$ for styrene butadiene, $k = 2 \cdot 10^7$ for sodium butadiene); f_{300} – stress at 300 % elongation; Θ – elasticity coefficient, equal to the quotient of the relative elongation at break divided by the relative residual elongation.

The above dependencies in most cases refer to the specific elastomer type or the specific test method, so their applicability is limited. For example, some researchers believe [1, 4] that formula (5) is applicable only to control deviations of the rubber abrasion parameters from the norm.

3. EXTERNAL FACTORS AFFECTING WEAR

The rubber wear intensity increases with pressure boost [5]. We describe this dependence by the equation for tread rubbers

$$J = J_1 \cdot p^X, \quad (6)$$

where J_1 – wear intensity at pressure $p = 0{,}1$ MN/m^2.

The x exponent in equation (6) can vary significantly depending on the abrading surface type and the rubber properties. The wear intensity is directly proportional to the pressure and $x = 1$ when tread rubbers wear on abrasive papers under conditions where the abrasive type of wear is realized. The x value changes within (1…8) range in the case of rubbers wear on smooth metal surfaces or metal meshes, i.e. under conditions of fatigue wear. The x value increases with the decrease in the sharpness of the surface protrusions.

Rubber abrasion is of high importance in the high-temperature range. As the temperature decreases, rubber abrasion decreases to the minimum, and then increases again as the test temperature approaches the glass transition temperature of rubber. This complex nature of the dependence of abrasion on temperature is because the wear mechanism changes. Abrasive wear occurs at low temperatures due to the increase in rubber rigidity, and wear by rolling – under high temperatures.

Relative slip is used as a parameter, which characterizes the kinematics of external friction by wheel rolling [3–5]. The wear intensity also increases with the same values of relative slip by an increase in the wheel angular velocity with the pneumatic tire. This is explained by the real friction path of the tread rubber increases with the same values of relative slip and an increase in the wheel angular velocity.

The experimental dependence of the wear intensity on the relative slip can be described by power equation of the form

$$J = k \cdot S^n, \quad (7)$$

where k – constant, which depends on the friction pair; S – value of relative slip; n – indicator, which depends on the wear mechanism of tread rubber.

The power-law relationship was established between the wear intensity and the friction power [4]

$$J \approx N_{fr}^n = F \cdot S \cdot V_0, \quad (8)$$

where F – friction force of tread rubber; V_0 – rotary velocity of the wheel with the pneumatic tire.

Dependence (8) in logarithmic coordinates for tread rubbers from different caoutchoucs is expressed by the straight line. The indicator values depend on the temperature, the abrading surface nature and the tread rubber composition. The surface nature of the tire tread changes – small tears, longitudinal scratches and cuts appear.

4. CONCLUSIONS

The wear intensity of tread rubbers for pneumatic tires used on road construction and mining machines is determined by the ratio of individual types, but the wear indicators can change significantly when the operating conditions change.

At the same time, the main dependencies are determined to establish the relationship between the wear intensity and the complex mechanical properties of tread rubbers, which are confirmed by road tests of machines.

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