OTS: 60-41,420

JPRS: 4053

21 September 1960

THE ROLE OF ROUGHNESS IN RUBBER FRICTION AND THE LAW OF FRICTION

By S. B. Ratner

- USSR -

Distributed by:

OFFICE OF TECHNICAL SERVICES
U. S. DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
205 EAST 42nd STREET, SUITE 300
NEW YORK 17, N. Y.

JPRS: 4053

CSO: 1051-S

THE ROLE OF ROUGHNESS IN RUBBER FRICTION AND THE LAW OF FRICTION

-USSR-

[Following is the translation of an article entitled "O role sherokhovatosti pri trenii reziny i o zakone treniya" (English version above) by S. B. Ratner in Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences USSR), Vol XCIII, No 1, Moscow, 1953, pages 47-50.]

(Submitted to Academician P. A. Rebinder, 22 August 1953)

In accordance with the theory of B.V. Deryagin (1), the force of friction depends on normal load N as per formula

$$F_1 = \mu_1(N + N_o) \qquad (1)$$

where μ_1 is a constant (true) coefficient of friction corresponding to the median value of the angle of micro-elevation, which "depends on the molecular-atomic coarseness of surface" (page 167); N_o - "the resultant of forces of molecular attraction between both bodies" (page 177), proportional to area of true contact of bodies in friction.

Quantity N_o must be added to the external load N in order to take into account the whole of the normal force active on the surfaces of true contact, where the micro-coarseness of bodies in friction is of consequence.

Deryagin's molecular theory correctly describes the role of those forces which come into being on the surfaces of true contact. But it does not take into consideration the role of the direct mechanical traction connected with rough (common) coarseness. However, such micro-coarseness is bound to lead to the additional component of the friction force

$$F_2 = \mu_2 N, \qquad (2)$$

where $_2$ is thefriction coefficient corresponding to the median angle of macro-elevation, which is connected with the rough coarseness (2). This alteration of the area of true contact, called forth [brought about] by changed macro-coarseness, will have a manifest bearing on the variation of quantity N_o (which may depend on N as well).

Thus, the full force of friction

$$F = (\mu_1 + \mu_2)N + \mu_1 N_o \qquad (3)$$

$$F = \mu_{\infty} N + F_o, \qquad (4)$$

where*

$$\mu_{\infty} = \mu_1 + \mu_2, \qquad (5)$$

$$F_o = \mu_1 N_o. \qquad (6)$$

Let us see to what extent this agrees with the experimental findings, the presence of two members in the law of friction (4) being beyond argument in all of the cases (3-7) and only the question of their connecting interrelationship to be considered. The following formula may be employed in this,

$$\mu = \mu_{\infty} + \frac{F_o}{N}, \qquad (7)$$

---

* If we consider the effect of macro-coarseness not only on the area of contact (i.e. on N_o, see above) but also on micro-coarseness (i.e. on μ_1) -- at the expense of the wedging action and the necessity of mutual interaction of contiguous macroprojections, then instead of μ_2 we may put $\mu_3 = \mu_2 \mu_1$ in our formulae. Then $F = \mu_1 [(1 + {}^2\mu_2)N + N_o]$ because $\mu_{\infty} = {}_2(1 = \mu_2)$. This result, obtained by us jointly with B.V. Deryagin during discussion of this article, will not alter subsequent conclusions which have a qualitative character.

which is the result of substitution (4) in the formula that serves for the determination of the computational coefficient of friction

$$\mu = \frac{F}{N}. \qquad (8)$$

In order to prove directly and quantitatively the validity of formula (3) presented by us earlier (3) in the form

$$F = \mu_{\infty} N + \mu_1 N_0, \qquad (9)$$

it is necessary to measure μ_{∞} and μ_1, and to show that $\mu_{\infty} > \mu_1$. Definition of μ_{∞} does not present any difficulties, because it can be discovered as a characteristic of the straight line in the processing of experimental data either in the coordinates F - N, per formula (4) or in coordinates $\mu - 1/N$, according to formula (7).

As a second characteristic of the straight line, quantity F_0 can also be determined. However, knowing F_0, one can arrive at μ_1 by formula (7) only if adhesion force N_0 is directly measured under exactly the same conditions under which F_0 was determined. This measurement, which can be conducted by employing the method of crossing lines, presents specific difficulties (4). Therefore we shall turn to qualitative testing of validity of formulae (3) and (9).

In accordance with the presented concepts, increased coarseness of metal must have a dual effect upon the friction coefficient. On one hand, μ_2 is supposed to increase, on the other - at the expense of diminishing contact - N_0 must diminish.

This effect is essential mainly for soft rubbers, especially at small loads (7); see formula (7). Therefore, when coarseness of steel is increased, we observe (see Table 1) at specific unit load P = 0.1 kgm/cm^2 a diminution of μ at the expense of decrease of N_0, and, at P = 10 kgm//cm^2, an increase in μ at the expense of increased mechanical traction (i.e. μ_2), which becomes especially apparent when the hardness of rubber is increased. Certain combinations of hardness of rubber and coarseness of steel permit an observation of tendency towards growth on the part of the friction coefficient when load is increased (see Table 1). An analogous picture appears also when the coarseness of brass and aluminum is increased.

Further, if formula (1) were applicable in the capacity of law of friction, i.e. if it could endure the whole of the force of friction (and not its part), then $\mu_2 \cong 0, \mu_\infty \cong \mu_1$, and consequently, there must be a strict proportionality between F_0 and μ_∞ in accordance with formulae (5) and (6). This can be expected in instances where macro-coarseness is very small - friction with lubrication (stearic acid or oleinic acid) of paraffin against glass (5), the friction of smooth criss-crossing threads of processed quartz - uncoated as well as covered by a thin coat of caoutchouc (4).

Such phenomenon should not be observable at "dry" friction of rubber, when μ_2 cannot be neglected in comparison with μ_1. In instances of friction between identical samples of rubber containing merely different quantities of various fillers, the particles of which become coated with a film of caoutchouc, quantity remained practically constant (7) because $\mu_2 = const$, because macro-coarseness is identical and microrelief changes insignificantly, within the limits of compatibility of caoutchouc with the filler (soot, graphite, chalk, bioxide of silicon).

A change of μ_∞ can be achieved at the effect of a change in surface of metal (a shift to a different variety or sample) or by introduction of such a large amount of filler that it will already overstep the limits of compatibility with caoutchouc and serve as a layer between the pair in friction. Both of these methods, which must lead to change in μ_∞, were actually observed (7).

When μ_∞ changes due to changed μ_2, i.e. switch of metal surface (see also Table 1) or even when a switch to plexiglass was made, a practical constancy of F_0 for rubber with a given amount of filler was observed, which speaks of the dominant role of rubber (as the softer component of the working pair) in the creation of microrelief of the friction surface.

μ_∞ can also be altered at the expense of change of μ_1, i.e. of the molecular relief, which can be realized when switching from one caoutchouc to another or from one metal to another (3,7).

Let us, at last, consider the role of temperature. According to the above, variations in the temperature of rubber are not supposed to effect macro-coarse-

Table 1

Coefficient of Static Friction of Rubber on Base SKN-26 Against Metals With Different Degree of Mechanical Finish of Surface

Soot Content in Parts by Weight	Hardness of Rubber According to Shor	Specific Unit Load in Kilograms /cm2	Steel			Brass		Aluminum	
			∇∇∇	∇∇	∇	∇∇∇	∇∇	∇∇∇	∇∇
10	52	0.1	0.96	0.81	0.80	1.32	1.18	0.99	0.99
		1.0	0.83	0.78	0.68	0.92	0.84	0.78	0.84
		10.0	0.43	0.48	0.54	0.56	0.49	0.49	0.52
45	71	0.1	0.74	0.61	0.64	0.97	0.95	0.60	0.82
		1.0	0.64	0.61	0.60	0.74	0.68	0.57	0.68
		10.0	0.43	0.59	0.67	0.41	0.43	0.57	0.67
120	96	0.1	0.44	0.61	0.42	0.33	0.72	0.57	1.06
		1.0	0.25	0.37	0.33	0.27	0.38	0.32	0.58
		10.0	0.27	0.40	0.52	0.26	0.51	0.33	0.74

ness μ_∞, but is of consequence for microrelief μ_1, and possibly also for N_0, when it comes to friction of rubber, the physico-mechanical qualities of which depend on temperature to a great extent. Insomuch as the heat-movement weakens the action of intermolecular forces determining the quantity F_0, we must expect that, when the temperature is higher, F_0 will be significantly smaller without an equally consequential decrease of μ_∞. The experiment (3) confirms this (see Table 2).

Accepting the following relationship, which flows from relaxational concepts about rubber (8)

$$F_0 = Ae^{U/RT} \qquad (10)$$

we obtain from Table 2 that $U \lessapprox 5$ kilocal/mole; this corresponds to the usual values of the energy barrier of van-der-Waals' forces.

Table 2

Effects of Temperature on the Constants of Formula (4) in the Case of Static Friction of Rubber on Base SKBM (Hardness According to Shor - 90) Against Steel (a) and on Alloy Containing Aluminum (b)

Temperature in °	μ_{∞}		F_0 in kg/cm^2	
	a	b	a	b
20	0.36	0.5	16	17
50	0.30	---	10	---
80	0.24	0.3	3	3

Such dependence continues only until further climb to higher temperatures leads to a significant softening of rubber, as a result of which the area of true contact gains sharply, and the computational coefficient of friction μ increases. Thus, in friction of rubber on steel at $P = 1$ kgm/cm^2, $\mu = 0.25$ at 80° (Table 2), $\mu = 0.23$ at 95°, and $\mu = 0.5$ at 110°, i.e., the curve runs through the minimum.

The author notes with gratitude the participation of B.V. Deryagin in the discussion of the results, and that of R.K. Gol'neva and G.P. Konenkova in conducting the experiments.

Received
16 VII 1953

REFERENCES

1. B. V. Doryagin, Chto takoye treniye (What is Friction), Pub. House of Academy of Sciences USSR, 1952; DAN (Doklady Akademii Nauk SSSR -- Reports of the Academy of Sciences USSR), 3, 93 (1934); ZhFKh (Zhurnal Fizicheskoy Khimii -- Journal of Physical Chemistry), 5, 1165 (1934).

2. V. D. Kuznetsov, Fizika tverdogo tela (Physics of the Hard Body), 4, Tomsk, 1947, p. 19.

3. S. B. Ratner, DAN, 83, 443 (1952).

4. B. V. Deryagin, S. B. Ratner, and M. F. Futran, DAN, 92, No 6, 1953.

5. B. V. Deryagin and V. P. Lazarev, Tr. Vsesoyuzn. konfer. po treniyu i iznosu (Works of the All-Union Conference on Friction and Wear), 3, 106 (1949).

6. I. V. Kragel'skiy and B. V. Deryagin, Ibid, 1, page 159.

7. S. B. Ratner and V. D. Sokol'skaya, DAN, 86, 121 (1952).

8. P. P. Kobeko, Amorfnyye veshchestva (Amorphous Substances), Pub. House of Academy of Sciences USSR, 1952; B. A. Dogadkin, Khimiya i fizika kauchuka (Chemistry and Physics of Kauchuk [Caoutchouc]), 1947.

10,065
10,123

-END-